TECHNOLOGY QUARTERLY

AND

PROCEEDINGS OF THE SOCIETY OF ARTS

Vol. XX SEPTEMBER, 1907 No. 3

# THE MARINE TYPE OF BEAM ENGINES[1]

By R. C. MONTEAGLE

Beam engines for the purpose of marine propulsion have not been discussed in detail very freely. This is somewhat remarkable when one considers their American origin and development, and is a matter of regret, as the subject is a highly interesting one and one which must prove of great value to the student.

The reason for this comparative absence of literature on a subject of such importance is probably to be found in the fact that the manufacture of these engines has been, and still is, monopolized by two or three establishments, these particular firms receiving orders from both the Atlantic and Pacific coasts, by reason of having in their possession the necessary drawings and patterns plus the experience in building the engines. This, taken in combination with the fact that the demand for this type of engine seldom at any time has exceeded the output capacity of these few favored shops, made it inadvisable that data and illustrations be given out for publication which might then be utilized by competitors.

I propose to give a general idea of the design of this type of engine, illustrated by some drawings made partially in detail.

Contrary to the belief of many, the beam engine is still being built occasionally for ferryboat propulsion and for river service. In all cases, whether these engines are equipped with surface condensers or

[1] A lecture delivered before the students of naval architecture.

jet condensers, they compare quite favorably in the matter of economy with compound engines The majority, however, are equipped with jet condensers and with air pumps of ample capacity. As a result, a vacuum as high as 28 inches has been obtained. When jet condensers are used the condensed steam and sea water are pumped overboard by the air pump, entailing a considerable loss of heat.

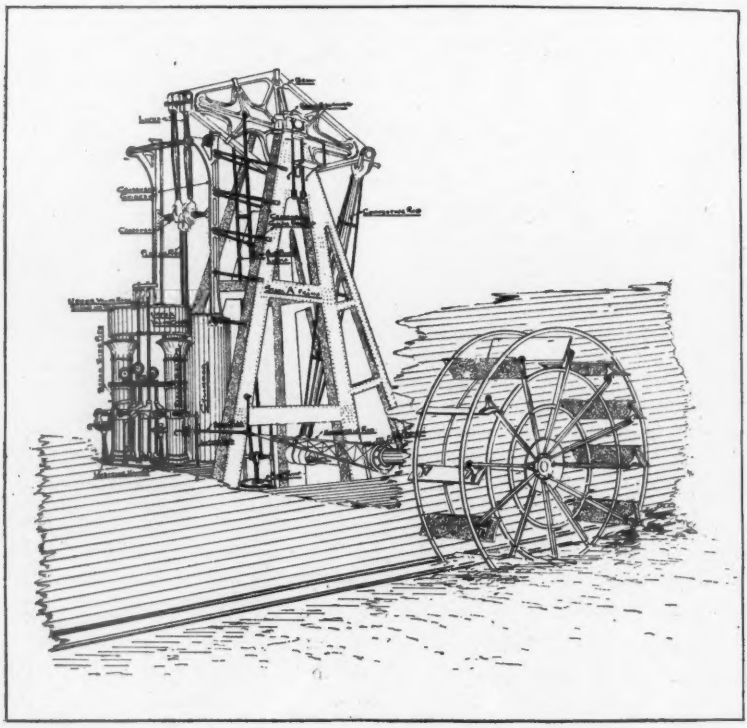

FIG. 1.—GENERAL ARRANGEMENT OF A BEAM ENGINE WITH STEEL A-FRAME

Boilers for single-cylinder beam engines are made to withstand a working pressure generally of fifty pounds per square inch. There have been instances where compound beam engines have been fitted in passenger steamers, the boiler pressure in such cases, of course, being raised. The cylinders are then arranged on one end of the beam, the connecting rod on the other. The high pressure cylinder

is placed next to the beam centre, or fulcrum, and has therefore less stroke than the low pressure cylinder. Practically no gain in economy over the old single cylinder was obtained in these cases, the economy, if any, being more than offset by the additional friction, initial cost, and subsequent cost of repairs.

As a consequence, beam engines for marine purposes, when they are built at the present time, are built with single cylinders and *generally* with jet condensers. This may easily be verified by a visit to any of our harbor ferryboats, one of which was built only last year.

Referring to Figure 1, an approximate perspective general arrangement of a beam engine is shown with steel A-frame. The great length of connecting rod is illustrated. This, however, is not abnormal in proportion to the stroke of the engine. In this drawing and the others to be thrown on the screen are shown only one steam eccentric and one exhaust eccentric. This I have done for the sake of simplicity.

All ferryboats and most other passenger steamers equipped with beam engines have two steam and two exhaust eccentrics, one set for going ahead, the other for going astern. In cases where there is only one ahead set of eccentrics the reversing is done entirely by hand, the gear being illustrated on another plate to be shown later. Short wipers on the hand gear shaft engage with lifting toes attached to the valve rods, these in turn being moved by a hand lever operated by the engineer. All beam engines are equipped with this hand gear, and when operating the engine near docks or making landings the hand gear is used for *either* going ahead or astern, the control being almost instantaneous.

I would call attention to the peculiar method of staying the crosshead guides, which is clearly shown in Figure 1. It is one which permits a certain amount of lateral movement, although not sufficient to cause trouble.

To the piston rod is attached a T-shaped crosshead which slides in vertical guides. This crosshead carries two links which connect to the pin on the end of the beam. From the other end is suspended the connecting rod, which is of a round cross-section, its greatest diameter being at the centre of its length. The extreme length of the rod renders it necessary to increase its diameter very materially at the centre, and, in addition to this, to truss it in the fore and aft direction. This truss is placed there principally to take up the excessive vibration, due to the variable compressive strains and to the oscillations of the rod, although the truss also adds materially to the strength of the rod.

Common dimensions for ferryboat engines are: diameter of cylinder, 52 inches; stroke, 12 feet, running about 550 feet piston speed. Taking the area of 52 multiplied by a possible initial pressure of fifty pounds per square inch, plus fourteen pounds for vacuum, we have a strain on one end of the beam of about 136,000 pounds. As the fulcrum is set in the centre of the beam, it follows that there is 136,000 pounds on the other end, the sum of these two being 272,000 pounds, or 136 tons. This load is transmitted through the pillow blocks to the gallows frame

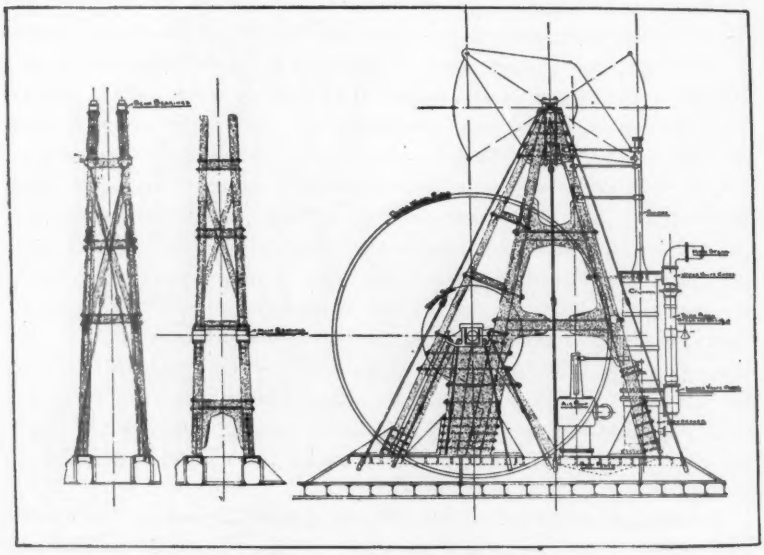

FIG. 2.—SHOWING A-FRAME OF WOOD

and through the gallows frame to the hull of the vessel, this being accomplished twice in every revolution of the engine, once in compression and once in tension. It is an extremely severe condition, but one which has been very satisfactorily met in the construction as indicated, or in a similar construction of wood.

During the past ten years feathering bucket paddle wheels have frequently been fitted in connection with beam engines, thus permitting the use of wheels of very much smaller diameter without loss of efficiency and at the same time reducing weight to a minimum.

Figure 2 shows the A-frame of the engine, or gallows frame, as it

is termed, constructed of wood. The frame is attached to the hull by means of plate brackets to deep girders running fore and aft, and of sufficient length to distribute the severe strains.

Wooden A-frames should be built of well-seasoned material thoroughly bolted and fastened, many well-fitted keys being driven between the timbers under the main bearings to prevent working and consequent loosening of the bolts. Long bolts with turn-buckles are fitted, connecting directly from the main and beam bearings to the deep keelsons. This is absolutely necessary, as the strains set up are alternately compressive and tensional every down or up stroke of the piston.

The gallows frame is now frequently constructed of steel, as shown in Figure 1, all the members being built up of plates and angles of box section. The gallows frame is connected to the hull framing, as shown. The condenser, with cylinder and steam chests superposed, rests on a bedplate connecting the two fore and aft girders. On the opposite end of this bedplate is placed the air pump, and through a channel way connecting the condenser and the pump flows the sea water combined with the condensed steam.

In practice it has been found that the air pump should have a capacity of from one-sixth to one-seventh that of the cylinder. This proportion should give a vacuum of about 27 inches if all joints are tight. The air pump is usually an iron casting lined with brass, and is worked from the beam. The foot valves and bucket valves are of pure rubber, with guards. Usually the main feed and bilge pumps are connected to the same crosshead which works the air pump, the stroke, therefore, being the same.

Figure 3 represents a cross-section of a vessel taken at the paddle wheels and showing the crank shaft in place. The method of supporting the outboard bearings of the wheels is illustrated, that is, by king-post and stays. The deep girders in the bottom of the vessel to which the A-frames are attached are also shown connected by angle irons to the floors.

Reference should be made to the projecting guards with which side wheel steamers are almost invariably fitted. At a short distance from the bow the main deck begins to extend beyond the line of the hull, and the width of the projecting part increases until it reaches the outside line of the wheel housing. Aft of the wheels it gradually diminishes again towards the stern. The superstructure and upper decks follow approximately the same outline. Vessels of 50 feet beam

are frequently as much as 90 feet over the guards, giving 20 feet overhang. Screw steamers are now frequently constructed on this plan, a notable and recent instance being the new Parson's turbine

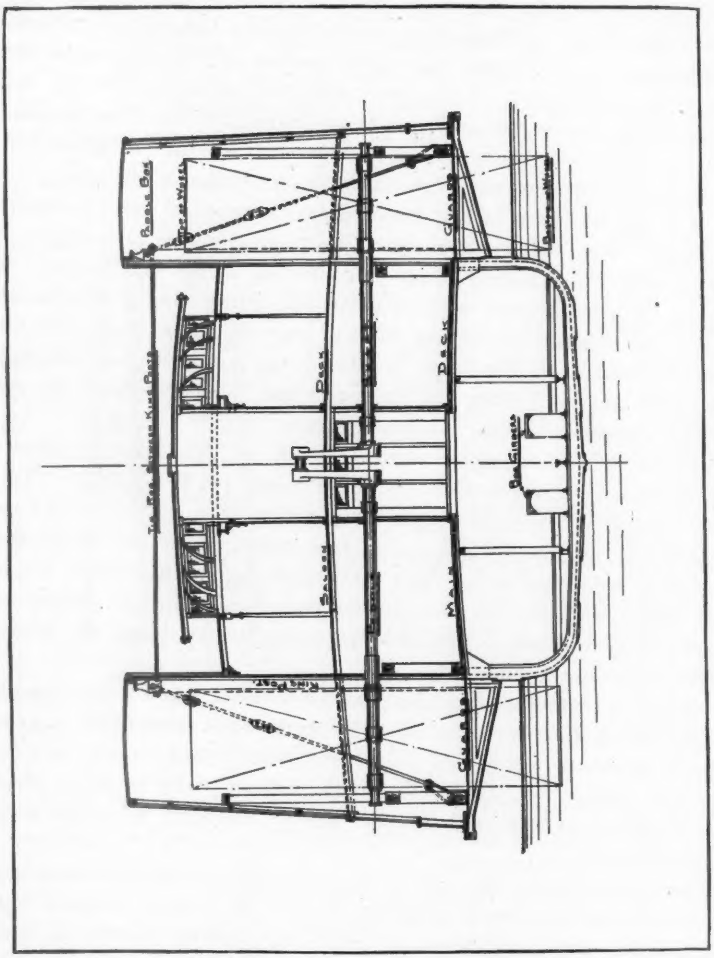


Fig. 3.—Cross-Section at Paddle Shaft

steamer *Governor Cobb*, now running from Boston and belonging to the Eastern Steamship Company. The old and still general method of supporting these guards is by means of diagonal struts connected

to the hull just above the load water line. In the *Governor Cobb* and many other sea-going vessels this has been modified. The frames and shell plating flare out from the normal beam at the water line to the extreme width at the guards, thus giving additional buoyancy and stability, and preventing the sea from striking upwards against the great flat surfaces of the guards, which must necessarily be a source of weakness and consequent danger. This weakness will undoubtedly be called to your attention should you ever make a trip on one of these vessels during heavy weather.

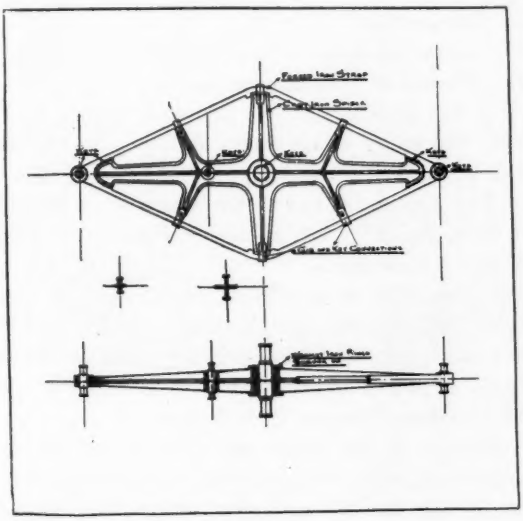

FIG. 4.— DETAIL OF BEAM

The principal object in having guards is to give deck room. In the case of the Hudson River passenger steamer *Mary Powell* and many others of the older type, the guards were utilized to support the boilers, the depth of the vessel under the main deck not being sufficient for this purpose. On the Pacific coast there are steamers with horizontal engines placed partly on these guards, each engine being entirely independent of the other, with an engineer on either side of the vessel. When required one engine goes ahead, the other astern, thus turning the vessel approximately in her own length.

Figure 4 shows the beam, which is made up of a cast-iron "spider,"

fitted carefully into a circumscribing band of wrought iron or mild forged steel, these two being bound together by many straps and keys, as indicated. The shaft and pins are held in position in the spider by four or more keys, the holes in the spider being bored out about 1 inch larger in diameter than the shaft or pins in each case. Wrought iron rings are then shrunk around the shaft hub on either side.

In making calculations for the strength of the beam, the whole strain is figured, of course, on the band. The fiber stress should be figured not to exceed 6,000 pounds per square inch, thus giving a large margin of safety and allowing for possible imperfections in the forging not visible on the surface.

Figure 5 shows the cylinder and cylinder heads, upper and lower valve chests, steam and exhaust side pipes, and jet condenser.

The valves are poppet valves, as shown in Figure 8, and it should be noted that the upper steam valves are larger in diameter than the lower, and that the lower exhaust valves are larger in diameter than the upper. The reason for this is the necessity of having a partially unbalanced valve, the difference in balance being in each case sufficient to close the valves when free.

The steel flat-plate expansion joints, shown between the upper steam chests and the tops of side pipes, perform their functions in a highly satisfactory manner, and it is very necessary that they should, the pipes being perfectly rigid and of cast iron. A leak in these joints rarely occurs, owing to the efficiency of this joint.

The temperature in the steam side pipe is that due to sixty-four pounds absolute, viz., 296°.8 F.; and the minimum temperature in the exhaust pipe is that due to, say, two pounds absolute, viz., 126.3 F., giving a possible difference of 170.5 F. Taking the length of the side pipes at 10 feet, which is quite normal, the coefficient of linear expansion for cast iron (of which they are invariably made) is .00000617. The increase in length of the steam side pipe over that of the exhaust in this case is, therefore, $10 \times 170.5 \times .00000617$ expressed in feet, which worked out will give an expansion of over $\frac{12}{100}$ of an inch. From this it is seen how absolutely necessary it is to have an efficient expansion joint. The principle upon which these expansion joints act is that of a diaphragm or flexible plate. Bonnets are placed on the fronts of the valve chests, so that the valves and valve seats may be put in position or removed, and also so that they may be examined. The injection water, as will be noted, impinges against the roof of the condenser, then

scatters and falls through the perforated plate, and in doing so breaks up and mingles with the exhaust steam, finally falling down into the channel connecting with the air pump.

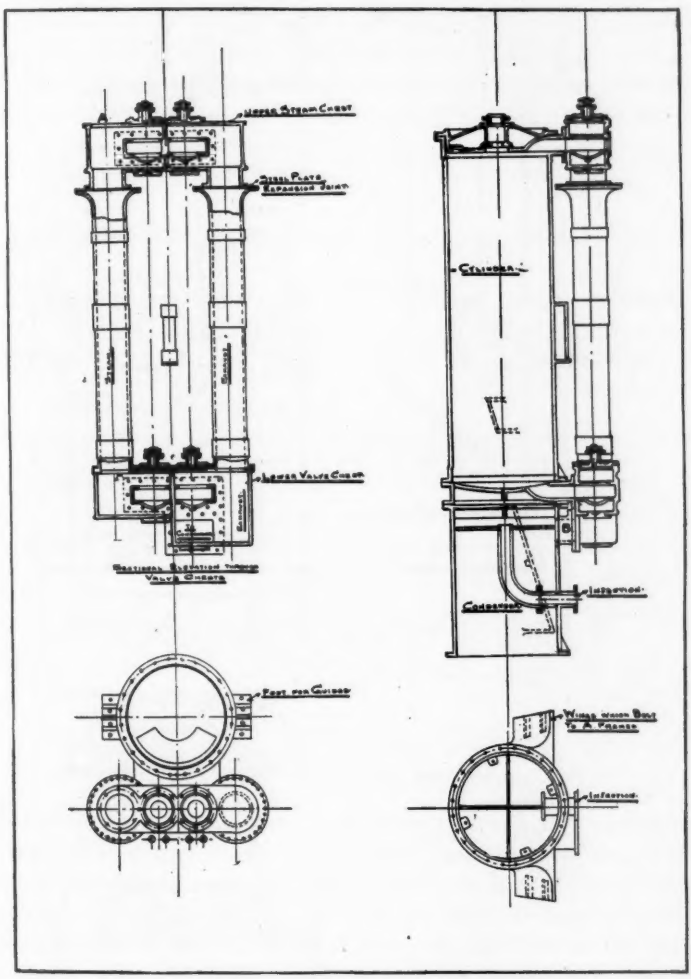

FIG. 5.—CYLINDER AND VALVE CHESTS

Figure 6 shows the general arrangement of the valve gear. You will note the foot lever C which operates the rods for throwing the hook rods D in or out.

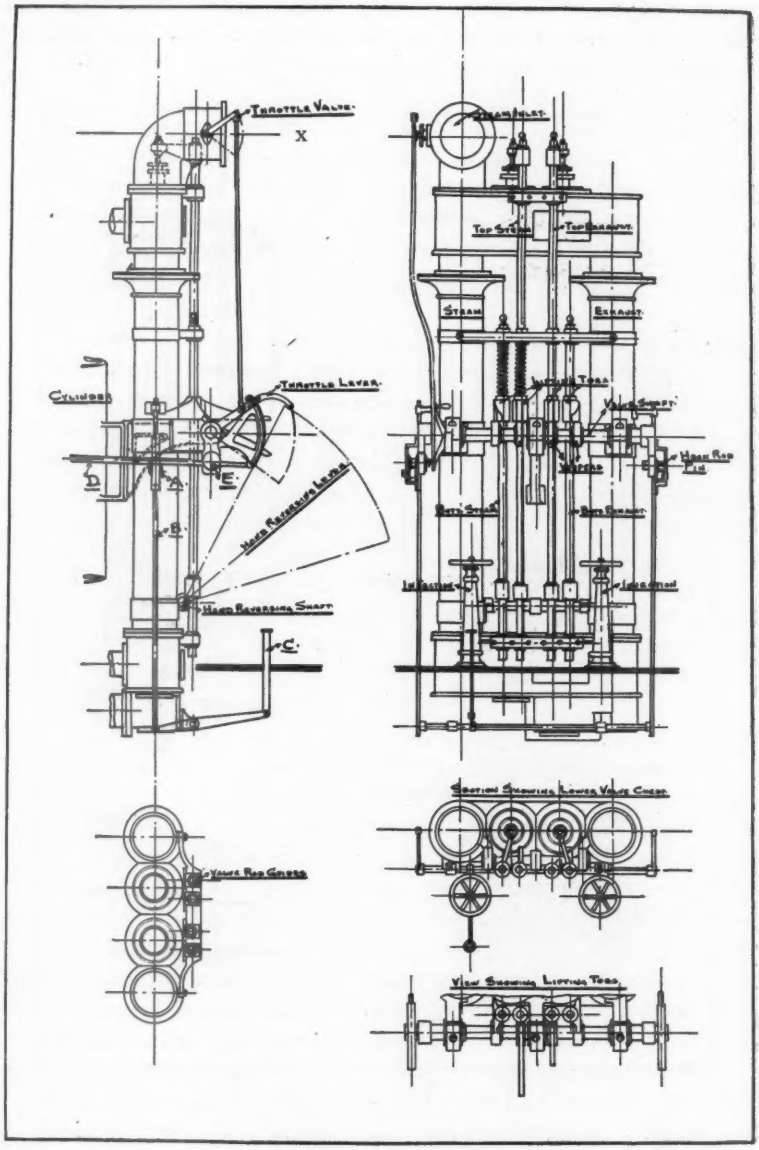


FIG. 6.—ARRANGEMENT OF VALVE GEAR

As I stated formerly, almost all beam engines constructed at the present time have a set of ahead and a set of astern eccentrics and rods. This drawing is made showing only one set. When it is desired to reverse the engine the foot lever is pressed down, forcing the rod B in an upward direction. This rod carries a small pulley A, which engages with the hook rod, lifting and holding it out of contact with the pin E, which is held firmly in the lever operating the valve shaft. The valve shaft is in two pieces, being cut in the centre bearing, one-

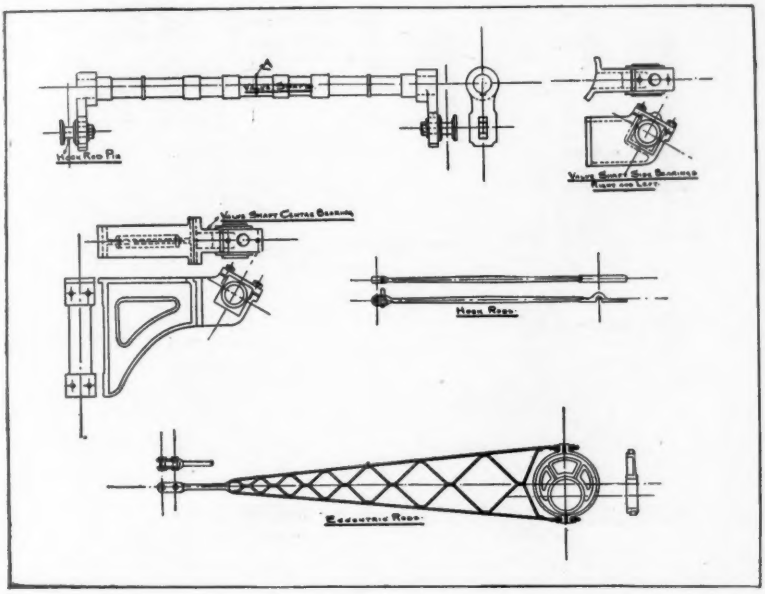


FIG. 7.—ECCENTRIC GEAR

half operating the steam wipers, the other half operating the exhaust wipers. The springs shown on the steam valves are placed there to cause a rapid closing of the valves. There are shown two stands for operating the injection valves. This is necessary, as there are always two injector valves fitted, one on the bottom and one on the side of the vessel. There is always a possibility of one strainer being rendered inefficient from various causes, and were there only one valve, in case of a stoppage to the strainer, it would be impossible to run the engine.

Figure 7 shows valve shafts and levers (the shafts being parted at

A), side and centre bearings for valve shaft, hook rods, eccentrics, and straps. The steam eccentrics are invariably given a greater travel than the exhaust eccentrics, although the steam valves have less lift than the exhaust valves, the object of this being to give a greater arc of travel to the steam wipers, so that the valves will open more rapidly.

Due to the extreme length of the eccentric rods, a truss method

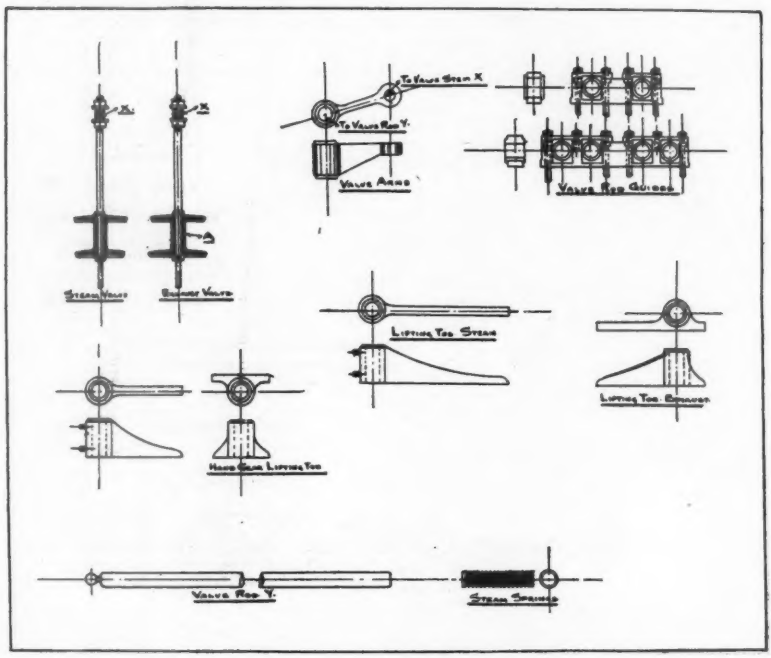


FIG. 8.—VALVE GEAR

of stiffening them has been adopted, as shown in the figure. It gives a fairly rigid construction with a minimum weight.

Figure 8 shows the steam and exhaust valves and stems, valve arms, valve rod guides, steam and exhaust lifting toes, hand gear lifting toe, valve rods, and springs. The lower steam valve being smaller than the upper, there is no difficulty in entering it through the upper valve seat. On the contrary, the lower exhaust valve being larger than the upper, it becomes necessary to part it at A, the lower part being put in place through the bonnet in the front of steam chest, the upper part being

put in place from the top, and finally the stem being put in place, holding the upper and lower valves securely together.

Figure 9 shows various positions of the wipers, lifting toes, and hook rods. At A the hook rod is disengaged and riding on the roller A, shown in Figure 6. At B the exhaust wiper is at extreme position, the valve being at its greatest opening. At the position C the steam valve is open, due to the amount of lead given. At D the steam wiper is at extreme position, the valve being at its greatest opening.

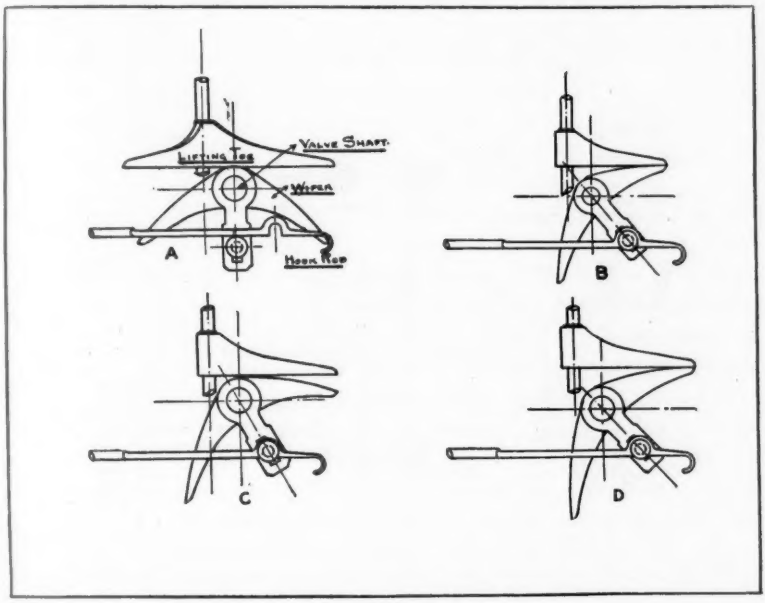


Fig. 9. — Lifting Toes

Figure 10 shows the crank shaft with radial wheel in position, also a detail of crank pin. In placing this shaft in position in the boat, the bearings are installed first, next the shafts are placed in position minus the cranks. Finally the cranks are put in place, as they usually must be shrunk on in the vessel. A fire is then carefully built, the vessel being duly protected by asbestos and iron where required, and the shaft end of the crank is heated to a sufficiently high temperature, hoisted between the ends of the shaft, and slipped over the end of the shaft in its final position.

A very important point to remember in designing one of these shafts is that the dimension A must be greater than the dimension B or the crank will not go in place.

The paddle wheels have each three sets of radial arms, with tapered ends fitting into sockets in the cast-iron disks shown, these disks being keyed to the shaft. The hub of each disk is hooped by two wrought iron bands, and the arms are bolted to the disks. Each set of arms has two or three concentric rings of iron, spaced as shown in the figure. Midway between each set of wooden arms is a radial iron arm with T-ends

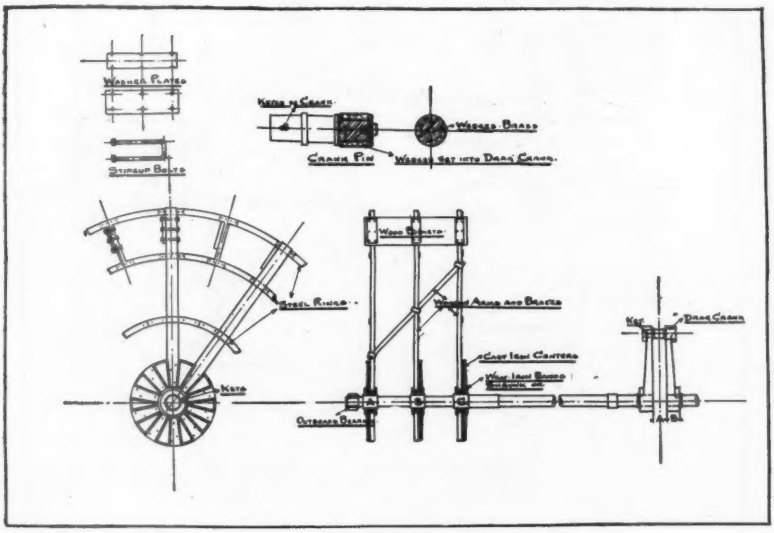


FIG. 10.—DETAIL OF PADDLE WHEEL

riveted to the two outer rings, each set of wooden and each set of iron arms carrying a float or bucket. About one-third of these buckets are made approximately 20 per cent. less in width than the others, the narrow buckets being placed nearest to the line of the dead centres, permitting the wheels to turn more easily at these points. The clearance between the ends of the buckets and the hull should be not less than 6 inches in any case.

The crank pin is driven hard into the driving crank and keyed. The other end of the pin is fitted with wedges into the "drag crank," as it is termed, the wedges being held in position by a disk and tap

bolt. Side-wheel steamers are generally constructed with light scantlings; the shafts are, therefore, subject to both bending and twisting strains. They should, therefore, be figured with a factor of safety of not less than ten. The cast-iron wheel centres are slipped on the shaft from the outboard end, C being larger in diameter than B, and B being larger in diameter than A. The centres are hung on tight-fitting keys, as shown in the end view. This wheel, as drawn, is what is termed a "radial wheel," with arms, diagonal braces, and buckets of wood, the rings and intermediate arms only being steel. It is very common practice nowadays to make the wheels of the feathering type and entirely of steel, including the buckets, which are then usually curved. The efficiency of the wheel is increased about 15 per cent. by so doing, provided that the wheel is properly designed.

I think it may be advisable at this point to go into the description of the valve gear a little more fully.

In beam engines the valve gear and mechanism for controlling the steam admission and exhaust are features of special interest. The arrangement of this gear was shown in Figure 6 and details in Figures 7 and 8. The steam cylinder, already shown in Figure 5, has diagonal wings cast on each side at the same angle as the gallows frame, to which they are well bolted. The top cylinder head is deep, with upper and lower webs, the stuffing box being formed in the cover and a brass neck bush being in the bottom. The top steam and exhaust passages connect with a cavity in the cylinder cover, there being a somewhat similar arrangement in the bottom cylinder head, the web of which is dished to a radius similar to that of the lower side of the piston. The cylinder is supported on the condenser, which also has inclined ribs, or wings, cast on the sides attaching to the gallows frame. In front of the cylinder, *i. e.*, on the engine room side, are two upright hollow cast-iron columns, or side pipes, as they are termed, having flaring tops. These are connected to the upper and lower steam and exhaust chests with a flat-plate expansion joint in each case at the top. There is a steam admission valve and an exhaust valve in each steam chest, a division plate separating them. The left-hand column, Figure 6, known as the steam chamber, connects the upper and lower steam chests, and the right-hand column connects the upper and lower exhaust chests. The lower exhaust chest connects directly with the condenser. The valves are of the double beat, poppet, or disk type, lifting vertically, the valve openings being shown clearly, although the valves are not shown in

place. Steam enters the upper steam chest from the boilers at X (Fig. 6) and down through the side pipe to the lower steam chest. As shown in Figure 5, there is a diaphragm cast in each chest dividing the steam from the exhaust; the exhaust from the top, therefore, passes down through the exhaust side pipe to the condenser.

The valve gear is essentially as follows. There are four eccentrics on the main shaft, two for steam, ahead and astern, and two for exhaust, ahead and astern. The eccentric rods operate the horizontal rock shafts, or valve shafts, Figure 6, on which are keyed four curved wipers. To the top of the stem of each valve is keyed a horizontal arm, the outer ends of which are attached to the vertical valve rods. On each valve rod is fixed a toe engaging with the wipers on the rock shaft. In front of the steam and exhaust chambers and below the rock shaft is the trip shaft for operating the valves by hand. This shaft has short wipers engaging with short toes on the valve rods. When this shaft is operated the upper steam and lower exhaust open together, and the lower steam and the upper exhaust likewise. The shaft is operated by a long starting bar inserted in holes in the shaft. Several large beam engines have been fitted with steam starting engines, giving ease and extreme rapidity in handling.

The stripper rods, as they are termed, which raise the ends of the hook rods clear of the rock shaft pins, are operated sometimes by hand and sometimes by foot, as shown here. By pressing the foot on this lever the stripper rods are raised, cutting off all connection between the hook rods and rock shaft. In ferryboats this is always done in making landings, the engine then being operated by the hand gear.

The lift of the valves should be carefully considered so that wire drawing may not occur. The amount of lift should be approximately one-fourth the diameter of the valve in each case, the area of the cylindrical surface due to the lift of the valve being equal to the area of the circle enclosed. Although the valves are always made self-closing, it has been found expedient to fit at least the steam valves with spiral steel springs so that they will act even more quickly, thus giving a rapid cut-off, and also so that the toes on the lifter rods will bear closely against the wipers, and so follow the movements of the latter. To the cylinder and to the two upright side pipes are attached three bracket bearings, which receive the rock shafts. These shafts are parted in the centre bearing, one shaft being operated by the steam eccentrics, the other shaft by the exhaust eccentrics. The outer end of each shaft has keyed

to it a crank arm in which is a slot, which permits vertical adjustment for the pin which engages with the ends of the hook rods, and hence changes the angular motion of the rock shafts. The hook rods connect the eccentric rods with the rock shafts. The eccentric rods being extremely long, it has been found advisable to truss them, which gives reasonable stiffness without extreme weight.

One of the most important problems to be considered in connection with the working parts of the beam engine is the proper sectional area of the connecting rod, and, in a lesser degree, the sectional area of the piston and air pump rods.

In the engine already considered, with cylinder 52 inches diameter and 12 feet stroke, fifty pounds maximum boiler pressure, and 28 inches vacuum, we found a load on the piston of approximately 136,000 pounds. As the fulcrum of the beam is in the centre of its length, we have an equal load on the connecting rod end of the beam. Lengths of beam engine connecting rods are made usually three times the length of stroke, which in this case would be 36 feet centre to centre. A connecting rod of this extreme proportion of length to diameter should be considered as a strut or column with rounded ends, the condition of fixed ends being too favorable. These rods are invariably stiffened by trusses extending the whole length, so that if the rod proper be allowed a factor of safety of 4, it is considered sufficient, the truss neutralizing most of the vibration and adding largely to its resistance to bending.

Under ordinary conditions, should this rod fail it will be by bending and not by direct crushing. A complete theory of this phenomenon is lacking, and the formula which has been here adopted is founded partly on theoretical and partly on empirical investigation. These investigations were made by Gordon. The values of the constants were also determined by Gordon. Where $P$ is ultimate load, $S$ sectional area in square inches, $h$ diameter at centre of length of connecting rod in inches, $l$ length of connecting rod in inches, $a$ a constant determined by experiment for ultimate strength $= \frac{1}{3000}$ for wrought iron, $f$ a constant for ultimate strength $= 36{,}000$ for wrought iron, the following equation gives the ultimate load.

$$P = \frac{fS'}{1 + 4a\dfrac{l^2}{h^2}}.$$

$S$ must be assumed and may be taken for trial as $\frac{\text{working load}}{2000}$ in the case of beam engines.

We found 136,000 pounds to be the working load.

Then $\frac{136000}{2000} = 68$ square inches sectional area of rod at centre $= S$. The diameter due to that area is approximately $9\frac{5}{16} = h$.

$$P = \frac{36000 \times 68}{1 + 4 \times \frac{.1}{3000} \times \frac{186624}{86.7}} = 632558.5 \text{ pounds ultimate load.}$$

$$\frac{632558.5}{136000} = 4.6 \text{ factor of safety.}$$

This formula I have used for a number of years in arriving at suitable dimensions for long connecting rods, piston rods, etc., and have found it to be exceedingly reliable.

Finally it may be of interest to know something of the early speed performances of passenger steamers fitted with beam engines.

One of the earliest day boats on the Hudson River was the *Albany*, built in 1826. She was 212 feet long overall, 26 feet beam, and 9 feet depth of hold. The cylinder was 65 inches diameter by 10 feet stroke, boiler pressure forty pounds per square inch, the wheels being 24 feet diameter. In 1839 this vessel was lengthened and the beam increased to 28 feet. In the year 1840, after the alterations, she made the trip from New York to Albany in eight hours thirty-three minutes, giving an average speed of seventeen miles per hour. The most notable speed performance in this connection is that of the *Mary Powell*, still on duty and one of the most efficient vessels of the Hudson River fleet today. The vessel was built in the year 1861, being, therefore, forty-six years old. Her length is 294 feet overall by 34 feet 3 inches beam by 64 feet beam over the guards by 9 feet depth of hold, with a draught of 6 feet. Her cylinder is 72 inches diameter by 12 feet stroke. The wheels are 31 feet diameter, with twenty-six buckets 10 feet 6 inches long and 18 inches wide, the dip being 42 inches. She has two boilers which are placed on the guards. The boiler pressure is forty-five pounds per square inch. In the year 1874 she ran from New York to Poughkeepsie, a distance of seventy-five miles, in three hours and nineteen minutes, actual running time, and giving an average speed of almost twenty-three miles per hour exclusive of stops.

The following are some of the particulars of this vessel.

| | |
|---|---|
| Length on water line | 286 feet |
| Length overall | 294 feet |
| Beam at water line | 34 feet 3 inches |
| Beam at guards | 64 feet |
| Depth of hold | 9 feet |
| Mean draft | 6 feet |
| Diameter of cylinder | 72 inches |
| Stroke | 12 feet |
| Cut-off | Half stroke |
| Average revolutions | 22 |
| Diameter of air pump | 40 inches |
| Stroke of air pump | 62 inches |
| Diameter of shaft | 15 inches |
| Diameter of wheel extreme | 31 feet |
| Length of buckets | 10 feet 6 inches |
| Width of buckets | 18 inches |
| Number of buckets on each wheel | 26 |
| Mean immersion of buckets | 42 inches |
| Number of boilers | 2 |
| Diameter of shell of boilers | 10 feet |
| Extreme length of boiler | 26 feet |
| Total grate surface | 152 square feet |
| Total heating surface | 2,660 square feet |
| Steam pressure | 45 pounds |

# ORE DEPOSITS OF THE EASTERN GOLD BELT OF NORTH CAROLINA[1]

By W. O. CROSBY

## Introduction

The crystalline belt of the Atlantic Seaboard, south of New York, attains its maximum breadth of 220 miles on the northern border of North Carolina; and it is in this state that it is most widely characterized by the occurrence of gold in workable deposits. Half a dozen auriferous belts have been recognized by Nitze and Hanna.[2] These are, in the main, coincident in position and trend with the northeast-southwest zones of metamorphic slates and schists, which, more than any other feature, give character to the geological map of North Carolina. The central gold belts, accompanying the main zone of slates and associated igneous rocks, are much the more important and persistent, and may be regarded as continuous northward across Virginia and southward into South Carolina. The eastern belt, on the other hand, is the shortest and, economically, one of the least important. Its extreme length does not exceed twenty-five miles, the narrow band of slaty rocks to which it belongs passing, both to the northeast and the southwest, beneath the coastal plain formations. But, although limited in area and production, this belt is, perhaps, comparable with the central belts or any part of the seaboard crystallines in the variety of conditions under which the gold occurs. It lies chiefly in the northeastern part of Franklin County and the northwestern part of Nash County, on the watershed of Fishing Creek and other tributaries of Tar River. The elevation is, roughly, between 400 and 500 feet; and the Tertiary peneplain has here an exceptionally perfect development, the reliefs separating the slightly incised stream courses consisting of broad, flat-topped peneplain remnants, bounded by gentle lateral slopes.

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[1] Reprinted from the Transactions of the American Institute of Mining Engineers.

[2] North Carolina Geological Survey, Bulletin No. 3, p. 15.

## General Geology

The eastern gold belt is separated from the central gold belts by the granitic rocks of the Raleigh, Louisburg, and Warrenton area; and these plutonic rocks are clearly younger than and intrusive in the associated metamorphic sediments. In traveling eastward from Louisburg or southeastward from Warrenton to the mining district, it is evident that we pass from a complex of granitic and gneissic rocks and various schists to an area of prevailing quartzites and siliceous slates, which are, however, freely intersected by the plutonics. Presumably, the sedimentary rocks are wholly of early Paleozoic age; and certainly their relations to the igneous rocks, so far as observed, are essentially identical throughout the district. The general line of strike of the sedimentary formations, as previously indicated, is northeast and southwest; and the prevailing dip is southeasterly at high angles. No effusive rocks, either acid or basic, have been observed in this district.

Almost universally, the rocks, of whatever kind, including even the hardest and most siliceous quartzite, are deeply rotted to normal saprolites; and both lithologic and structural features are thereby greatly obscured. Furthermore, the upland or peneplain surface is very generally overspread by a mantle of fine quartz sand. In part this sand appears to be simply the saprolite phase of the quartzite; but elsewhere it is horizontally stratified and includes, at least basally, layers of quartz gravel; and it seems then to require correlation with the Columbian formation.

## Genetic and Structural Relations of the Gold-Bearing Formations

*Sedimentary and Plutonic Rocks.*—First in order of age come the sedimentary rocks, consisting chiefly of normal quartzite, grading through siliceous slates into metamorphic clay slates or phyllites. Intersecting these terranes in a highly irregular manner, and often transversely, is the complex of plutonic rocks, among which diorite, normal granite, and pegmatite are especially prominent.

The diorite is believed to be here, as in so many other plutonic regions, an earlier, peripheral, basic phase of the same body of magma which has yielded the granite; and it is clearly cut by dikelike masses of granite. Both the diorite and granite exhibit marked variations in texture and composition. They are frequently gneissic; and a sheared and chloritized part of the diorite is the chloritic schist of other writers.

The pegmatite, on the other hand, is clearly a later phase of the granitic magma, and forms irregular dikes in all the other rocks of the complex, both igneous and sedimentary. So far as noted, it is of highly acid composition, consisting chiefly of megacrystalline quartz, acid feldspars, and muscovite.

*Veins.*—In part the pegmatite is highly quartzose, and shows an unmistakable tendency to grade into quartz veins, which are the feature of the complex of most particular interest so far as the occurrence of gold is concerned. This tendency and the occasional occurrence of coarsely crystalline muscovite, identical with that of the pegmatite, in otherwise normal auriferous quartz veins leave no room to doubt the genetic relation of the pegmatite dikes to some, at least, of the quartz veins, or that the gradation is a fact.

Large areas of the complex of sedimentary and plutonic rocks are traversed by an irregular network of quartz veins, varying in width from a line to 50 feet or more, but mainly rather narrow, and individually highly variable in size and trend. They are, without exception, massive and glassy; and bands, combs, vugs, or other indications of crustification or of endogenous origin are conspicuous by their absence, as are also the selvage phenomena of normal fissure veins. The veins have not, as a rule, been worked below the oxidized zone, although this is shallow; but indications of sulphides below the water level are very meager and often wholly wanting. Aside from the oxidation of the scanty sulphides, the quartz veins have, in general, survived the rotting of the enclosing formations, and are now traceable, *in situ* and essentially intact, through the residuary detritus or saprolite.

In the central gold belts of North Carolina the writer long since recognized two essentially distinct types of auriferous veins: (1) Massive quartz veins of varying and often considerable size; devoid of definite selvage, combs, and vugs; relatively, and often absolutely, barren of sulphides; and the average gold tenor low to very low, but highly irregular or pockety, the gold being free, mainly coarse and nuggety, and thus especially favorable for the enrichment of placers. (2) Relatively narrow quartz-sulphide veins, with the normal structural features of true fissure veins; and relatively high and even gold values, the gold being rarely coarse and only to a limited extent free.

The veins of the first class are believed to be, in general, the older; to be, in part, approximately contemporaneous with the granitic rocks; and hence to have been formed under essentially plutonic conditions by

so-called magmatic waters and to admit of correlation, to some extent, as the end term of the pegmatites; while the veins of the second class are the product of the more normal circulaton of the ground water at less than plutonic depths, and represent the leaching of the upper and less metamorphic zones of the earth's crust by waters largely or chiefly of meteoric origin.

The veins of the second type form the basis, now and then, of continuously profitable mining operations; but those of the first type are rarely payable except locally and transiently, where a pocket or bonanza is encountered. These are the "specimen" veins, which are most profitable to man where they have been extensively mined by the slow processes of erosion and the product concentrated in placer deposits. Again, having been formed under approximately plutonic conditions, and not being in any large degree dependent upon sulphides for their values, the veins of the first type are not, to any important extent, subject to secondary enrichment by downward leaching. In other words, their marked variations of value are primary and do not, as in the sulphide veins, admit of close correlation with depth, both the coarseness of the gold and its uneven distribution being consonant with a quasi plutonic origin, which has allowed the principle of segregation to accomplish its most perfect work, bunching the gold in pockets within the veins, and in nuggets within the pockets.

Obviously, the veins of the eastern gold belt belong to the first or nonsulphide type; and in this fact we find the key to the history of gold mining in this district. Also, it may be noted here that the best values are found, as a rule, in the narrower veins, the wide ones being of little or no economic interest.

*Impregnations.*—The immediate country rock, be it granite, diorite, or quartzite, of the quartz veins and veinlets is often slightly impregnated with gold; but it is doubtful if the degree of impregnation is ever sufficient to make the undecomposed hard rock a practical ore. With the saprolite, however, the case is somewhat different, since it is easily mined and requires no crushing. The mineralized or impregnated granite saprolite, known locally as the "white belt," usually carries the best values. We are considering here a type of deposit—metasomatic impregnation and replacement—which elsewhere in the Southern Appalachian region has proved of exceptional importance, from a mining point of view. But in this eastern gold belt it is, even when reduced to the condition of saprolite, of little economic interest, the values being,

in general, still too low to justify metallurgical treatment, and the proportion of coarse gold too low to permit a large saving by placer methods. In comparison with the veins, the impregnations are noteworthy for the finely divided condition of the main part of the gold and for its relatively even distribution. As in the veins, however, sulphides are meager or wholly wanting. In brief, the impregnations partake of the character of the veins which they border, save that the gold is prevailingly fine instead of coarse, and hence unfavorable for the enrichment of placers.

*Placers.*—Long-continued and extensive erosion, resulting in the peneplanation of this region, set free a notable amount of the coarse gold of the quartz veins and effected its concentration in residuary placers adjacent to the outcrops of the veins from which it was derived. Subsequently, during the Columbian submergence, this residuary gold was still further concentrated, as a marine placer, in the basal layers of the Columbian gravels. Finally, during the erosion of the gravels and the trenching of the underlying peneplain by the modern valleys, the gold again became a residuary deposit; but in large part, also, it was carried down the slopes and experienced a further concentration in the gravels of the stream beds. Thus, for the surficial as for the bedrock formations we may recognize two principal types of auriferous deposits: (1) residuary and marine placers, representing a primary, vertical concentration in a plane, during the development of the peneplain; and (2) stream placers, representing a secondary, horizontal concentration in a line, during the trenching of the peneplain.

The bedrock deposits—veins and impregnations—are, as we have seen, of little economic interest, except locally for the saprolite phase; but where nature has mined these formations by cubic miles and concentrated the gold in the ratio of thousands into one, the results may be very interesting, although the deposits are quickly exhausted and do not afford a basis for long-lived mining.

## Mining Notes

The writer's observations in the eastern gold belt were chiefly confined to three properties; but these appear to illustrate satisfactorily the normal range of conditions for the district.

*Alston Mine.*—This property is a part of the plantation of Edward Alston, in Warren County, about 16 miles southeast of Warrenton,

and on the northwestern margin of the gold belt. Gold was first discovered here in 1847 through the finding of a nugget in the road by one of Mr. Alston's servants. The situation is a low knoll of saprolite in which may be readily recognized, in order of age, quartzite (sometimes micaceous and garnetiferous), diorite (fine, dark, and chloritic), granite (fine, white, and micaceous), dikes of pegmatite, and a plexus of quartz veins. The superficial, residuary deposit or placer has been worked over an area of an acre or more, yielding a considerable amount of coarse gold. Several of the quartz veins have been prospected to the water level (25 to 30 feet). These have also yielded good values; but they are much too small to admit of profitable mining. The fine, impregnating gold is chiefly confined to the vicinity of the quartz veinlets in a band (dike) of granite saprolite 20 to 30 feet wide, forming the "white belt" of this property. In the pan, this impregnating gold appears as numerous very minute colors of remarkably uniform size, a condition highly characteristic of this type of deposit and making impossible any large recovery by placer methods.

*Sturgess (Portis) Mine.*—This mine, the best known and most productive of the eastern gold belt, is situated near Ransom's Bridge in the northeastern corner of Franklin County, at an elevation of about 100 feet above Shocco Creek. The extent of the workings and the variety of deposits which they exhibit make this property exceptionally favorable for the study of the geologic relations of gold in this district.

The predominant bedrock formation is the diorite, which is, at most points, thoroughly rotted, yielding, superficially, a deep red soil. Cutting through the diorite saprolite are occasional dikes of fine-grained granite saprolite (white belts). One of these is only 4 to 5 feet wide, while another is above 70 feet.

Both the diorite and granite are traversed by a network of very irregular quartz veins, of all sizes up to 2 feet thick. They are said to be generally auriferous, with pockets running thousands of dollars to the ton, the small veins being relatively the richest. The granite saprolite, or white belt, also carries appreciable, and, in part, workable values, although the minute subdivision of much of the gold prevents a high recovery.

As usual in the eastern gold belt, the surficial deposits have been most productive. These include: (1) a considerable area of Columbian gravel, the basal layer of which, resting unconformably upon the diorite and granite saprolites, contains workable values; (2) a still larger area

of residuary placer, where the Columbian gravel has been removed by erosion and the gold left directly upon the surface of the underlying saprolite; and (3) the stream gravels in the bed of a minor water course or "branch," the valley of which trenches the saprolite.

Thus we may recognize here, in obvious genetic relation, five available sources of gold: two original or bedrock sources—the quartz veins and the accompanying impregnations of the granite saprolite or white belt; and three secondary or placer sources, marine, residuary, and stream.

The Columbian gravel is still largely intact; but the residuary and stream deposits have been worked to the verge of exhaustion; and to these may be credited a large part of the total product. In part, also, the quartz veins and white belts have been worked to depths of 20 to 30 feet, the saprolite being washed and the quartz trammed to a twenty-stamp mill and crushed. The chief handicap to the operations has always been the lack of water, which can be had in quantity or under pressure only by pumping. Were a gravity supply available, hydraulicking of the entire property down to the "branch," followed by the milling of the quartz thus mined, and the subsequent cleaning up of the "branch" with a dredge would, doubtless, yield interesting results.

*North Carolina Placer Mine.*—The property of the North Carolina Dredging Company is on the same "branch" which traverses the Sturgess mine, and immediately below the latter. The valley floor is here several hundred feet wide, with a very low gradient; and the conditions are in every way favorable to the operation of a dredge. A low dam has sufficed to create the necessary pond for a Robinson chain-bucket dredge with a daily capacity of 1,000 cubic yards, working 14 feet deep. The pay streak is a layer of clean gravel 6 inches to 3 feet thick, on bedrock, with a layer of tough clay over it. Some gold is found in the silty overburden; but it is mainly in the gravel; and the values are fairly even across the valley, although greatest near the middle. The gold is mainly fine to very fine, or such as might have been transported by this feeble stream during a recent period of elevation, when it was flowing on bedrock.

# THE BROADER FEATURES OF THE GEOLOGIC HISTORY OF NORTH AMERICA IN DIAGRAM

By HERVEY W. SHIMER

THE following article is an attempt to simplify and make easy for remembrance the main changes in the relative position of sea and land, and to indicate the general effect of this upon the climate, fauna, and sediment. The discussion of these changes and their corresponding effects is based largely upon views advanced by T. C. Chamberlin. The first part deals with a general discussion of these theories, while the second applies them by diagram to the North American continent.

The alternation of the subsidence of much of the land beneath the ocean with its reëmergence as a land surface is a familiar geologic fact. It is borne witness to by many unconformities between marine sediments, as well as by the alternation of thick and widespread deposits of limestone with strata of clastic origin—sandstone and shale. For example, the limestone formations of the Ordovician, middle Silurian, mid-Devonian to mid-Carboniferous, and lower Cretaceous are usually followed and preceded by clastic sediments or unconformities.

This alternation of subsidence with reëlevation was given a theoretic reason by Chamberlin in his discussion of the "Ulterior Basis of Time Divisions."[1]

He suggests that after the folding of portions of the earth's crust into mountains "in the process of periodic readjustment of the earth to its internal stresses," *i. e.*, shrinkage, "portions of the crust are thrust up to heights notably above the plane of isostatic equilibrium, and that these portions gradually settle back toward equilibrium by virtue of the slow fluency or quasi-fluency of the rocks." The settling back, which takes place very slowly, gradually permits the sea again to cover much of the land. This advance of the sea over the low-lying portions of the land is aided by the transference of material by rivers and waves from

[1] Journal of Geology, 1898, **6**, 450.

the land into the ocean, thus "displacing an equivalent amount of water and raising the sea level proportionately."

The clear and comparatively shallow waters of the broad seas enabled multitudes of lime-secreting organisms to thrive, and while their remains built up great beds of limestone, they at the same time added to the water, and naturally also to the air, great quantities of $CO_2$.[1] For when the organism, such as a coral polyp, takes the $CaCO_3$ from the water to build up its hard parts, it sets free the combining $CO_2$ which is necessary to hold it in solution, since in order to dissolve, for example, limestone and keep it in a soluble state as it is in sea water, some $CO_2$ in addition to the $CaCO_3$ of the rock is necessary, and hence when this is again returned to the rock condition, as it is in the coral, this extra $CO_2$ is set loose. As this deposition of limestone and consequent release of $CO_2$ is taking place in the broad epicontinental seas all over the world at the same time, there would result a notable increase in the carbon dioxide of the atmosphere. Carbon dioxide, in common with water vapor, possesses the peculiar property of being able to retain the sun's heat, but unlike the latter, it is active at any earth temperature. Thus, with an increase of this constituent in the earth's atmosphere, there would result an increase of heat, and with an increase of heat an increase of humidity; for where there is a stable higher temperature, more moisture can be held in suspension.

On the other hand, when the seas upon the continents are gradually withdrawn by the deepening of the ocean basins and by mountain folding, the release of $CO_2$ would be replaced by its consumption, since in the wearing down of the land areas $CO_2$ is necessary in getting much of the material into a transportable, *i. e.*, soluble, form. It is consumed in the decay of crystalline as well as of sedimentary rocks. Hence during times of enlarged and higher continents there would be a decrease in the carbon dioxide of the air and a consequent lowering of the temperature, with a *pari passu* drying of the atmosphere. At such times the broad, shallow seas would be withdrawn from the land, and the continental shelves be reduced to very narrow zones, over practically all of which clastic sediments would be deposited. In such waters many of the lime-secreting organisms, such as corals, could not live. There would thus be formed during this period no limestone beds, except in a few local areas, but instead, great thicknesses of sandstone, shale, etc. This would be

[1] T. C. Chamberlin: "The Influence of Great Epochs of Limestone Formation upon the Constitution of the Atmosphere," Journal of Geology, **6**, 609.

deposited around the margins of the continents, as well as upon the continents themselves—the latter through the agency of overflowing (aggrading) rivers and also in enclosed basins. With these there would be deposits of salt and gypsum, owing to the low humidity. The color of much of the sediment would be red, since in being deposited upon the land where little water was present to cause leaching, the iron of the original rocks would remain in the sediment and would be changed through oxidation to the red ferric state. At the same time, the higher mountains would cause greater local precipitation; and if the temperature of one of the places of greater winter precipitation were sufficient to cause the falling moisture to take the form of snow, more might fall during winter than could be melted during summer, and thus glaciers would form.

There would thus in the earth's history be alternating periods. During periods of continental depression great deposits of limestone would form most of the sedimentary rocks, for even along the margins of the land, clastic deposits would be much less abundant than at times when the land stood higher. At the latter part of such periods when long continued without continental elevation, erosion would have reduced most of the land to a state of peneplanation, and thus the deposition of clastic sediment would be reduced to a minimum. The temperature and humidity would be high. Individuals of marine life would be exceedingly abundant, and this fauna would be more or less similar all over the world, *i. e.*, cosmopolitan (as in Ordovician, mid-Silurian, Carboniferous, etc.), owing to the presence of broad continental shelves and the absence of many land barriers, thus favoring free migration.

On the other hand, during the sea's withdrawal and the accentuated height of the land due to mountain folding, very little limestone would be deposited, but instead, widespread and thick beds of sandstone and shale. Much of this sediment would be red, as, for example, that of the Permian and Triassic. The temperature and humidity would be low, causing deposits of gypsum and salt, such as those of the upper Silurian, the Permian to the Trias, and the Quaternary to recent. Likewise, at times, the presence of glaciers would be favored during periods of most marked land elevation, as in the Permian and Quaternary. Marine life would be excessively decreased in abundance, this result necessarily following upon the narrowing of the shallow water tracts where most marine forms live, *i. e.*, the continental shelves and other epicontinental seas. The faunas that persisted would soon become provincial in char-

acter, since the narrow continental shelves and the broad land areas would prevent free migration. The land life, on the other hand, would find this its time of free migration, as is seen in the wide occurrence of similar land animals during the Permian to the Trias, the Tertiary to the Quaternary; and as is evidenced likewise in the wide introduction of modern land plants between the lower and upper Cretaceous, as noted in the Morrison and Dakota formations, and in the striking similarity of the Permian plants of South America, South Africa, Australia, and India.

The above discussion in its relation to the broader geologic history of North America[1] may be represented by the following diagram.[2]

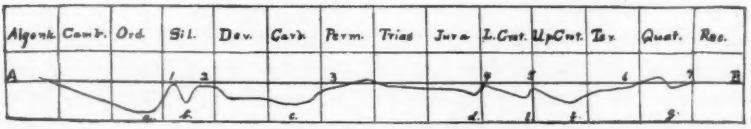


DIAGRAM TO REPRESENT THE PRINCIPAL OSCILLATIONS OF THE NORTH AMERICAN CONTINENT

The letters (*a*, *b*, etc.) indicate times of submergence of much of the continent; the figures, times of elevation or enlargement. The curves are drawn with reference to the present size of the continent, which is represented by the line *AB*.

The line *AB* represents the present height of the continent. The position of the curves was determined by letting the present land surface of the continent be represented by 1, and comparing this with the land surface during the preceding geologic eras as shown by the spread of marine sediment. This data is based largely upon the geologic maps of "Chamberlin and Salisbury's Geology," Volumes 2 and 3.

The lower portions of the curves (*a*, *b*, *c*, etc.) thus indicate times when much of the North American continent was covered with comparatively shallow seas, in which were laid down the widespread and thick deposits of limestone. The marine faunas of such periods were very abundant and quite similar in widely separated regions, making easy the correlation of the strata of these ages. For example, the Ordovician of Australia and eastern North America are very similar.

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[1] For the sake of simplicity only the broader elevations and depressions, affecting largely most of North America, are noted here.

[2] I am indebted to Mr. A. O. Christensen, Massachusetts Institute of Technology, 1907, for some suggestions of this diagram.

The upper portions of the curves indicate times of elevation of the continent; those parts that go above the line *AB* are necessarily doubtful, as it is at present impossible to say how much larger than its present size the continent ever became. These upper curves (1, 2, etc.) represent either an absence of all sediments or the presence of clastic sediments, these latter deposited either upon the land or along its borders. Either while the land is being elevated or, more usually, while it is being again depressed, the clastic sediment is laid down at the sea margins, and by the progressive advance of the seas upon the land this sediment gradually becomes deposited upon much of the land area. These upper portions of the curves also indicate the more arid and colder times, and hence here occur the most important deposits of salt and gypsum. At such times, likewise, the marine faunas are most decreased in numbers and most provincial, thus making it difficult to correlate the strata of different regions. The upward swings of the line mark the times of the geologic revolutions closing the limestone epoch and inaugurating the clastic. Thus 1 represents the time of the Taconic revolution; 3, the Appalachian; 4, the Sierra Nevada; and 6, the Rocky Mountain or Laramide. At 2, 5, and 7 the withdrawal of the seas does not seem to have been accompanied by any great mountain folding.

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CONTRIBUTION FROM THE
SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION
OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

# THE PREVENTION OF STREAM POLLUTION BY STRAWBOARD WASTE[1]

BY EARLE BERNARD PHELPS

## INTRODUCTION

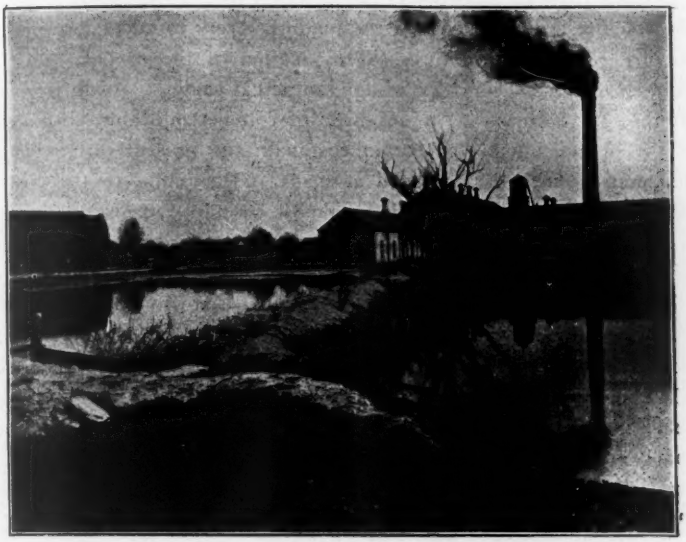
THE disposal of the waste liquors resulting from the manufacture of strawboard forms one of the most important problems connected with the prevention of stream pollution. In 1900 the total production of strawboard in the United States was 157,534 tons at 59 factories. For each ton of strawboard manufactured there were discharged into the streams about 65,000 gallons of waste liquor that contained 1,173 pounds of straw and mineral matter and 490 pounds of lime. The total waste discharged into the streams in 1900 amounted to 10,239,710,000 gallons of liquor, containing 184,777,382 pounds of straw and mineral matter and 77,191,660 pounds of lime. This enormous waste was discharged by 59 plants of various sizes, but as most of these mills are along small streams the resulting pollution is very apparent. Some idea of the amount of this pollution may be obtained from Plate I, *B*. The baled straw shown is a three months' supply for a mill having an output of 30 tons a day. In three months one-third of this straw will be discharged into the stream as waste matter.

The problem of the disposal of the waste water has been studied by Professor R. L. Sackett, of Earlham College,[2] and the present investigation is a continuation of the work of Sackett along new lines. In approaching the problem it is necessary to keep constantly in mind the economic conditions affecting the industry. The low selling price of the

[1] Reprinted by permission from Water-Supply and Irrigation Paper, No. 189, United States Geological Survey.

[2] Water-Supply and Irrigation Paper, No. 113, United States Geological Survey, 1905, pp. 9–35.

PLATE I



*A.* VIEW OF STRAWBOARD MILL

*B.* PILES OF BALED STRAW

One-third, by weight, will be wasted in three months

product, the immense volume of waste water necessary, and the fact that competition between strawboard and other forms of cheap board is active, make it quite impracticable for the manufacturers to adopt any process involving serious expenditures. The solution of the problem must be sought in a process which will show an actual saving. Aside from the matter of the recovery of by-products of commercial value, this means that the process must compete in cost with the present unsatisfactory sedimentation methods employed at many of the mills, to the cost of which may reasonably be added the almost constant expense of lawsuits and injunction proceedings, the latter in some cases causing the closing of the mill.

As a result of this study it has been found that sedimentation of the waste water for a short period, followed by filtration thru sand at high rates—the so-called mechanical filtration, but without coagulants—will produce an effluent from which more than 90 per cent. of the suspended organic matter has been removed. This effluent, while not ideal, is probably purified to such an extent that, allowing a factor of safety of 2 for impurities in the stream, it may be discharged into streams having a minimum flow of twice the discharge of the mill without producing a nuisance. The cost of filtration by this process, after the initial cost of installation, is practically reduced to the cost of pumping the wash water. The final result is a heavy sludge, whose volume is less than 5 per cent. of the initial volume of the waste. Ultimate disposal of this sludge could be made either by discharge over land for spontaneous evaporation, by evaporation by means of artificial heat, or by filter pressing. The sludge has some value as a fertilizer, and there are also certain commercial uses to which it seems to be adapted.

## THE MANUFACTURE OF STRAWBOARD

The following description of the manufacture of strawboard is taken from Professor Sackett's paper:[1]

### Steaming in Rotaries

"The straw is first subjected to a cooking process by steam and lime. A large ellipsoidal rotating steel boiler called a 'rotary' . . . is filled

[1] Water-Supply and Irrigation Paper, No. 113, United States Geological Survey, 1905, pp. 13–15.

with straw, which is then cooked down with steam, then again filled and cooked down until the rotary boiler has been completely filled. The process of filling a rotary occupies from six to twelve hours. The final charge consists of about 6 tons of straw and 30 bushels, or 2,100 pounds, of lime in the form of milk. This mixture is then rotated and cooked under 40 pounds of steam pressure for twelve hours. . . . This apparently severe chemical and mechanical action results in a rapid softening of the woody fiber and in the reduction of the straw to a dark yellow, pulpy mass. This 'stock,' as it is called, is stacked in piles 10 to 15 feet high to drain. Concerning the action which takes place in the rotaries, the *Journal of the Society of Chemical Industry*[2] says:

"'The chemical action of the milk of lime on the incrusting materials surrounding the straw fiber is not a vigorous one. These incrusting materials are not completely, nor, indeed, to a great extent, separated from the cellulose. The mineral matter remains in the product practically untouched, and if any less quantity than that corresponding to the percentage in the original straw operated upon exists in the prepared pulp, it is due rather to the washing after digestion than to any solvent action of the milk of lime. Milk of lime under certain conditions has a bleaching action upon the straw. It neutralizes the organic acids usually found when fibrous plants are heated for any length of time in the presence of water.'

"The yield of pulp at this point will be from 75 to 80 per cent. of the weight of the original material. . . .

"The material is allowed to stand in these piles for twenty-four hours or more to drain. After it is thus drained it contains about 50 per cent. of water and from 6 to 7 per cent. of lime. This is equivalent to from 12 to 14 per cent. of lime in the dry straw. Since the original charge of lime and straw was in the proportion of 2,100 pounds of lime to 14,100 pounds of straw and lime, or about 14 per cent. lime, practically none of the latter has drained out with the condensed steam. This drainage from the stock piles forms but a small part of the waste sewage. It is straw colored and very turbid, carrying a small quantity of fiber broken fine in the rotaries.

### Washing

"This process is much more drastic, and it is here that the great volume of waste is produced.

[2] For February 28, 1894, p. 101.

"The stock is run thru washing machines for the purpose of removing the lime. . . . The washing machine consists of an oval channel about 3 feet wide, around which the stock travels, being supplied with copious volumes of water. Across this channel is placed a cylinder, 42 inches in diameter and 42 inches long, having longitudinal ribs or flanges about three-fourths of an inch square in section and three-fourths of an inch apart. Meshing with this, like the teeth of geared wheels, is an idler, below, of similar size and form. These wheels, revolving, lift the water and straw to a level several inches higher than that in the oval channel, whence it flows by gravity halfway around its course to a point where it meets a revolving brass screen of fine mesh, thru which a part of the water escapes, carrying with it the finer particles of fiber and free lime. The remaining straw, with additional volumes of fresh water, now passes many times thru the rolls, which further mash and break the fiber, and around to the screen, where more straw, lime, and water escape. . . .

### Drying

"After the washing process the straw, with a considerable volume of water, is led to a train of rolls, consisting of three parts—first, the wet end; second, the hot rolls; third, the trimming and cutting machine. As it comes from the washers the material is run into vats, where it is mixt with large quantities of water and past over hollow cylinders having fine wire-cloth faces, which allow the water to escape, leaving the fiber on the surface of the cylinder. The fiber is then taken by woolen felts, which are prest down on the surface of the cylinder. This makes a web of paper on the felt. The pulp, which is now about one-third straw and two-thirds water, travels up and down, over and under a double train of hot rolls, heated by steam that is carried in thru hollow bearings. As the pulp passes on thru the train it is constantly prest and dried, until finally it is separated from its cloth support and goes to the trimming machine, where it is cut into sheets of proper size. It now contains about 10 per cent. of water and a small quantity of lime. The board is manufactured in many thicknesses and weights. Just before it is trimmed it may be coated on one or both sides with a thin paper facing or finish."

## THE DISPOSAL OF WASTE LIQUOR

### Method in Use

At present, so far as can be learned, the only method of treating the waste liquor in actual use by the manufacturers is that of prolonged sedimentation in open fields. The overflow water from these fields is not satisfactorily clarified at all times of the year. During cold weather it is fairly clear and can be discharged without serious harm. During the summer, however, a very offensive fermentation takes place in the accumulated sludge, giving rise to objectionable odors and blackening the water. At such times the aim is to hold all the waste water in the ponds, trusting to evaporation and to the storage capacity of the ponds until cold weather again relieves the situation and the increased flow of the stream permits a discharge of the surplus water stored. The most serious objection to this process, which seems to be satisfactory to riparian owners below, is the fact that these ponds are continually filling up with a soft mud, which destroys their function as sedimentation basins and renders them useless for other purposes. The time must come, even in the most favorable situation, when additional land cannot be afforded for this purpose. A second objection is that the accumulated sludge is held for years and slowly putrefies. The organic matter of the waste is but slightly nitrogenous and is fairly stable. It probably contains some reducing sugars capable of rapid fermentation if kept in concentrated form and if given at the same time some nitrogenous matter. The slow decomposition of the stable straw material supplies the necessary nitrogen, and the result is a very rapid multiplication of the putrefactive organisms and an accompanying offensive putrefaction. Laboratory experiments have shown that the soluble sugars by themselves, as found in a filtered sample of the waste water, do not ferment or decompose, and that even the unfiltered waste is not subject to a quick putrefaction such as characterizes sewage matter. In fact, bottles have been stored for over a year without any evidence of fermentation, and it may very reasonably be held that the necessary nitrogen comes largely from the bottom of the ponds, rather than from the sludge itself. Inspection of the stream below one of these ponds showed that, while putrefaction was barely noticeable and not at all offensive in the pond itself, the admixture of some of this water with that of a small brook, highly polluted with the refuse of a slaughterhouse, had immediately a very offensive result. Investigation of the condition of the streams below

these mills reveals the fact that the most serious nuisance generally occurs at a point very remote from the mill itself. It is directly caused by the slow decomposition of material deposited in the bed of the stream. The conditions are doubtless aggravated by the simultaneous precipitation of other polluting substances, notably sewage, brought about by the free lime of the strawboard waste.

The effective solution of the problem lies in the rapid separation of the solid matter from the dissolved sugars and lime and a subsequent dilution of the latter so that they shall be innocuous. The insoluble material when dry is entirely stable. The present system, therefore, is not only unsatisfactory from the economic side, but it works on a wrong principle for satisfactory purification in that it encourages putrefaction.

The cost of these ponds at four of the larger mills of the United Box-board and Paper Company, as stated by an official of that company, has been, in round numbers, to date, $10,000, $15,000, $18,000, and $8,000. In the last case the results were still unsatisfactory, and after a considerable expenditure on other experiments the company has been obliged to close this mill.

## Proposed Methods

### *Centrifugal Separation*

Centrifugal separation of the solid matter from the liquor was tried at Tiffin, Ohio, in 1904. It has not been possible to obtain more definite information concerning those experiments than is contained in the trade papers of that time. It is understood, however, that the results were quite satisfactory, but that the cost of operation was prohibitive. The account referred to (see *Paper Trade Journal,* February 2, 1905) states that the effluent was clear and colorless and that the residue was found by analysis to be valuable as a fertilizer.

### *Precipitation with Carbon Dioxide*

As a result of his investigations Sackett concluded that plain sedimentation would remove about 10 per cent. of the suspended solids in twenty-four hours, and that during the ensuing twenty-four hours the additional removal was very slight; that good purification could be effected by chemical precipitation only by using sulfate of aluminum in excessive amounts and at an entirely prohibitive cost; that sulfate of iron gave inferior and unsatisfactory results; and, finally, that by a

process of precipitation with carbon dioxide and lime an average removal of 85 per cent. of the suspended matter could be effected.

The process recommended by Sackett consists in (*a*) saturation of the waste water with carbon dioxide to form bicarbonate with all the lime present; (*b*) addition of lime equal to that already present to form a normal carbonate; (*c*) sedimentation of the precipitated carbonate and consequent dragging down of some of the organic matter; and (*d*) filtration of the resulting clarified liquor thru sand at rates of 500,000 to 2,000,000 gallons per acre per day. This process has never been used by manufacturers so far as the writer is aware.

It does not appear from Sackett's report that he tried the simpler but equivalent process of saturating one-half the total volume with carbon dioxide and then mixing with the other half. Such treatment would doubtless have precipitated the calcium fully as well, with a saving of one-half the carbon dioxide and all the lime required by the process recommended. An examination of the analytical data shows that the removal of suspended organic matter accomplished by the precipitation and sedimentation processes varied from zero to 75 per cent., with a mean value of 37 per cent. Experiments on plain sedimentation, made by the writer both in the laboratory and on a large scale in the field, show it to be equally efficient for the removal of suspended organic matter. The fact is that the precipitated carbonate of calcium is very finely divided and has no value as a coagulant. The process is valuable to remove the lime, if that be desirable. It hardly seems, however, that the value of discharging a lime-free effluent into the hard waters of the Middle West is at all commensurate with the cost of treatment.

## LABORATORY INVESTIGATIONS

### Chemical Study of the Soluble Matter

Several barrels of the strawboard waste liquor were shipped to Boston from one of the mills of the United Box-board and Paper Company, and on this material a series of investigations was carried out. Sackett's experiments with various coagulants were repeated and his results confirmed. It was found that the poor results obtained with any but excessive amounts of iron or aluminum sulfate were due to the presence of a substance in solution which forms soluble combinations with those metals. This substance was isolated by precipitation with hydrochloric

acid, and after repeated purification was found to have the following properties: It is an organic acid, probably related to the humic or ulmic acids of the soil and peaty waters. It exists in the waste water as a calcium salt, having partially neutralized the free lime used in the digestion. It is precipitated by strong acids, coming out as a dark-red substance which turns brown on slow oxidation in the air. It can be redissolved in a solution of sodium carbonate, giving a garnet-red solution. It dissolves in alcohol, giving a deep-red color, but oxidizes to a brown, insoluble substance. Its calcium and aluminum salts are not soluble when prepared from the insoluble acid, but the acid cannot be precipitated from its solutions by these metals. It appears that there are formed colloidal suspensions of the calcium and aluminum salts. The solutions have a bright yellow color and colloidal appearance. The iron compound is similar but of a green color. The sodium salt appears to be soluble and to dissociate into deeply colored acid ions.

A second substance isolated from the waste has the following properties: It is soluble in water and not precipitated by any of the common precipitants, including alum, ferrous sulfate, lead acetate (normal or basic), carbonates, hydrates, or acids. It is responsible for a large part of the color of the water and cannot be removed by any practical method.

These two substances with the lime make up the greater part of the dissolved material. They are entirely stable and do not undergo putrefactive change when stored in the incubator, either alone or mixt with varying proportions of tap water. In addition to these substances small amounts of reducible sugars are present. The amount is so small that in any material dilution of the liquor the dilution of these sugars will prevent their manifesting themselves as putrefactive agents. These sugars are probably responsible for the slow fermentation in the sedimentation fields after the lime has been sufficiently removed to allow the action to proceed.

## Precipitation Experiments

Substances in suspension may be removed by filtration or by sedimentation. When the material is finely divided or of low specific gravity, either process may sometimes be assisted by the application of suitable coagulants. These tend to clot the small particles into larger flakes, and by their own greater density carry the clotted material to the

bottom. Two chemical substances are required, as a rule, to produce the necessary precipitation, one of which is generally the calcium bicarbonate found normally in the water. This calcium salt reacts with the sulfates of certain metals, notably iron or aluminum, to produce the sulfate of calcium and the hydrates of the corresponding metals. In the present case there is a large amount of free lime in solution. It would seem, therefore, that precipitation might be brought about by the addition of either copperas or alum. Experiments showed that copperas failed to react at all and that fair results could be obtained with alum, but only at a prohibitive cost. As will be seen in the accompanying tables of results, the removal of organic matter by alum was much better than that obtained by plain sedimentation.

RESULTS OF PRECIPITATION EXPERIMENT ON STRAWBOARD WASTE

| Sample. | Suspended Solids. | |
|---|---|---|
| | Present. | Removed. |
| | Parts per million. | Per cent. |
| Raw waste | 1,350 | . . |
| Waste after two hours' sedimentation: | | |
| With coagulant* | 120 | 91 |
| Without coagulant | 560 | 59 |

* The coagulant used was alum in the proportion of 10 grains of sulfate of aluminum per gallon.

Increasing the amount of aluminum sulfate gave practically the same result. Smaller amounts gave indefinite and at times negative results. The use of 10 grains per gallon of sulfate of aluminum at 1 cent a pound would represent a cost of about 43 cents per ton of finished product of the mill. The studies on the nature of the dissolved material already referred to explain these poor precipitation results with alum. Soluble compounds are formed with the organic acid, instead of aluminum hydrate, the desired coagulant.

Experiments were made with carbon dioxide according to Sackett's procedure, and his results were confirmed. There was but a slight removal of suspended organic matter—about 30 per cent.—which could be produced equally well by plain sedimentation. In fact, under actual working conditions sedimentation was found to be even more effective.

### Sedimentation Experiments

In a study of plain sedimentation it is important to know the rate of sedimentation and how this varies with the time. With satisfactory data on this point it is possible to estimate the amount of clarification which may be expected to result from any given period of sedimentation, and to establish the most suitable period for the case in hand. It was observed early in this work that apparently a large portion of the suspended solids settled out in a very short time, and that to all appearances further improvement was extremely slow. The determinations of the total solids given in the following table show that there is no practical advantage in sedimentation for a period of much over one hour.

Effect of Sedimentation on Strawboard Waste

| | Suspended Solids. | |
|---|---|---|
| | Present. | Removed. |
| | Parts per million. | Per cent. |
| Liquor at beginning of experiment . . . . . | 1,344 | . . |
| Supernatant after one hour . . . . . | 548 | 59 |
| Supernatant after twelve hours . . . . . | 494 | 63 |

### Summary

As a summary of the laboratory investigations, it may be said that the removal of the dissolved coloring and other organic matter and the lime in an economical way is impractical; that by plain sedimentation a removal of suspended material practically as good as the best removal observed with the use of a coagulant can be accomplished; and that a sedimentation period of one hour is sufficient for the removal of about 60 per cent. of the suspended solids, a longer period increasing this removal but slightly. For the removal of the remainder of the suspended matter there remains but one process—filtration. It was therefore decided to make an actual field test of this method of purification. The very large amounts of suspended matter to be handled seemed to eliminate at the outset the possible use of slow sand filtration, so that it was obvious that mechanical filtration at high rates and with some provision for removing the accumulated sludge from the surface of the filters was the only system applicable to the problem.

## FIELD INVESTIGATIONS

### Acknowledgments

In March and April, 1905, a visit was made to one of the mills of the United Box-board and Paper Company, at Urbana, Ohio. Every opportunity was given the writer to make a thoro study of the processes of manufacture, and it is here desired to make suitable acknowledgments to Mr. Rush E. Evans, division manager, and to Mr. D. C. Amerine, superintendent, for the many courtesies extended, both on that occasion and during the subsequent visit for the installation of an experimental plant.

### Amount of Water Used

It was found that conditions were favorable for measuring the entire volume of waste water, as it left the mill in a waste flume. As a check on these measurements, observations of the rate of operation of the pump were made, all the water used being pumped from a large well under the mill.

A rectangular flume, whose mean width was 1.96 feet, was used for these measurements. A distance of 100 feet was measured off in a portion where the slope was practically constant. To determine the velocity of flow at various elevations in the flume, a float was used which was nearly as long as the width of the flume and was provided with vanes underneath, so that it always floated squarely across the flume. The following observations are the mean of a large number made at various elevations of water in the flume.

Mean Depth, Velocity, and Flow of Waste Water in Flume of Mill of United Box-board and Paper Company, Urbana, Ohio

| Depth of water. | Velocity of flow. | Area of cross-section. | Flow. |
|---|---|---|---|
| Foot. | Feet per second. | Square foot. | Cubic feet per second. |
| .19 | 3.1 | .37 | 1.1 |
| .25 | 3.8 | .49 | 1.9 |
| .29 | 4.0 | .57 | 2.3 |
| .31 | 4.2 | .61 | 2.6 |
| .33 | 4.3 | .65 | 2.8 |
| .37 | 4.5 | .72 | 3.2 |

These values of the depth and the corresponding flow were then plotted. The most probable line was drawn thru them, and that curve was used as the true rating curve of the flume in the subsequent calculations.

During the two hours from 10.45 A.M. to 12.45 P.M., March 30, a test run was made to determine the total flow. The following readings of the elevation of the water in the waste flume were made, and from these readings has been calculated the total flow for the two hours.

FLOW OF WASTE WATER IN FLUME OF MILL OF UNITED BOX-BOARD AND PAPER COMPANY, URBANA, OHIO, MARCH 30, 1905

| Time. | Depth. | Flow. | Flow for Fifteen-Minute Period. | |
|---|---|---|---|---|
| | | | Mean rate of flow. | Total flow. |
| | Foot. | Cubic feet per second. | Cubic feet per second. | Cubic feet. |
| 10.45 A.M. | .29 | 2.3 | . . | . . |
| 11.00 A.M. | .29 | 2.3 | 2.3 | 2,100 |
| 11.15 A.M. | .33 | 2.8 | 2.6 | 2,300 |
| 11.30 A.M. | .33 | 2.8 | 2.8 | 2,500 |
| 11.45 A.M. | .33 | 2.8 | 2.8 | 2,500 |
| 12.00 M. | .33 | 2.8 | 2.8 | 2,500 |
| 12.15 P.M. | .38 | 3.4 | 3.1 | 2,800 |
| 12.30 P.M. | .36 | 3.1 | 3.2 | 3,000 |
| 12.45 P.M. | .33 | 2.8 | 3.0 | 2,700 |
| Total | . . | . . | . . | 20,400 |

This total flow of 20,400 cubic feet in two hours represents an average flow of 2.69 cubic feet per second.

A few measurements were made of the water running in the waste flume when the beaters were not running and again when the paper machine was stopt. The flow from the machine was found to be fairly constant at 1.4 cubic feet per second, and the beaters were found to discharge amounts of 1.2 to 1.8 cubic feet per second, depending on the number of beaters in operation at the time.

During the test run observations of the rate of operation of the

pump were made at short intervals. The pump was a double-acting duplex Smith-Vaile pump, with water cylinders 14 inches in diameter and with a stroke of 15 inches. Slip being neglected, the capacity of the pump is, therefore, 1.335 cubic feet per stroke, or 5.340 cubic feet per complete revolution. Following are the observations made on the pump and the calculated rate of pumping:

DISCHARGE OF PUMP AT MILL OF UNITED BOX-BOARD AND PAPER COMPANY, URBANA, OHIO, MARCH 30, 1905

| Time. | Revolutions per minute. | Discharge. | Time between observations. | Discharge of Pump between Observations. | |
|---|---|---|---|---|---|
| | | | | Mean. | Total. |
| | | Cubic feet per second. | Seconds. | Cubic feet per second. | Cubic feet. |
| 10.45 A.M. | 31 | 2.28 | . . | . . | . . |
| 11.00 A.M. | 30 | 2.67 | 900 | 2.43 | 2,457 |
| 11.15 A.M. | 30 | 2.67 | 900 | 2.67 | 2,403 |
| 11.30 A.M. | 30 | 2.67 | 900 | 2.67 | 2,403 |
| 11.45 A.M. | 30 | 2.67 | 900 | 2.67 | 2,403 |
| 11.55 A.M. | 30 | 2.67 | 600 | 2.67 | 1,602 |
| 11.56 A.M. | 40* | 3.58 | . . | . . | . . |
| 12.25 P.M. | 40 | 3.58 | 1,800 | 3.58 | 6,444 |
| 12.45 P.M. | 38 | 3.57 | 1,200 | 3.48 | 4,176 |
| Total pumped | . . | . . | . . | . . | 21,888 |

* Changed.

During the test four of the seven rotaries were filled. Two hundred and fifty cubic feet of water are required for each rotary, or 1,750 cubic feet for the seven. Since all seven are filled only once in twenty-four hours, the water used in this process amounts to 73 cubic feet per hour for the whole day. The water so used during the two hours of the test was, however, 750 cubic feet, an excess of 604 cubic feet over the normal mean consumption. The amount pumped must, therefore, be corrected by this amount. The elevation of the water in the supply tank was 1 foot greater at the end of the test than at the start. The diameter of the tank is 12 feet. This storage amounts, therefore, to 113 cubic feet, and must also be applied as a correction. A small stream

of water was being wasted from the engine condenser. This stream was roughly estimated by float measurements to be about 0.3 cubic foot per second, or 2,160 cubic feet during the two hours of the run. These three corrections amount to 2,888 cubic feet, which is to be subtracted from the total pumped, 21,888 cubic feet, leaving a net pumpage of 19,000 cubic feet for two hours, or 2.64 cubic feet per second, a result in close agreement with the 2.69 cubic feet per second measured in the waste flume.

## Raw Material and Finished Product

During this test run, careful weighings were made of the amount of finished board produced. The figures were as follows:

Product of Mill of United Box-board and Paper Company, Urbana, Ohio, for Two Hours, March 30, 1905

| | Pounds |
|---|---|
| Gross product | 4,841 |
| Waste and trimmings | 196 |
| Net product | 4,645 |

Dividing the total amount of waste liquor, 20,400 cubic feet, by the amount of net product gives 8,780 cubic feet, or, roughly, 65,000 gallons per ton of product. As the daily product of this mill is about 30 tons, about 1,900,000 gallons of waste water are discharged each day.

The charge of one rotary was carefully weighed. There were used 133 bales of straw, of an average weight of 102 pounds, or a total of 13,600 pounds of straw. The amount of lime was weighed, but the weight was somewhat in excess of the average amount used, as determined by the total weekly consumption of lime. The latter figure, which is 2,100 pounds per charge, will therefore be used. The total amount of straw used in the 7 rotaries is accordingly 95,200 pounds per day, and of lime, 14,700 pounds per day. Subtracting from this the 60,000 pounds of finished product leaves a waste of 35,200 pounds of vegetable and mineral matter from the straw and 14,700 pounds of lime, which is carried off each day in the 1.9 million gallons of water. Calculated into parts per million, these figures give about 2,400 parts of straw material and about 1,000 parts of lime. Analyses of average samples of the waste water gave about 600 parts of calcium or 840 parts of lime per million. The difference is due partly to the loss of lime during the draining of the digested pulp and largely to impurity of the lime.

### Character of the Machine Water

Determinations of the lime were made on the well water and on the various waste waters. It was found that the greater part of the lime is washt out in the beaters, and that the water from the machine contained but little lime in excess of that in the raw water. The actual figures were:

Calcium in Waste Water

| | (Parts per million) |
|---|---|
| Well water | 238 |
| Beater water | 1,164 |
| Machine water | 380 |

A rough determination of the impurities was made by precipitating the lime and organic matter, with a large excess of alum. A 6-inch column of the beater water gave a layer of precipitate an inch thick, while the amount obtained from the machine water was too small to be measured.

### Mechanical Filtration

In May, 1906, a small experimental filter was installed at this mill, in order to obtain some practical data on the efficiency of treating the waste by mechanical filtration. The filter and accessories were loaned by the New York Continental Jewell Filtration Company, of New York, thru the courtesy of Mr. R. E. Milligan, assistant general manager, and the expenses of shipment and installation were borne by the paper company.

#### *Description of the Filter*

The filter used is shown in Figure 1. The waste water, after passing the regulating butterfly valve, divided into two streams and entered the bottoms of the two sedimentation tanks. These tanks were of cypress, each having a diameter of 4 feet and a depth to the overflow line of 3.2 feet. The capacity of the two was 603 gallons. The water was delivered to the tanks thru half-inch holes in the sides of risers extending to the surface. The vertical distribution was, therefore, very uniform. Vertical baffles caused the water to flow completely thru the tanks, and a funnel-shaped overflow collected the clarified water from the surface of each tank and delivered it to the surface of the filter. The filter proper was of galvanized iron, set upon a cast-iron base, provided with a false bottom of fine brass screening. The diameter of the filter was 20 inches, and its total depth to the false bottom was 5 feet. Suitable

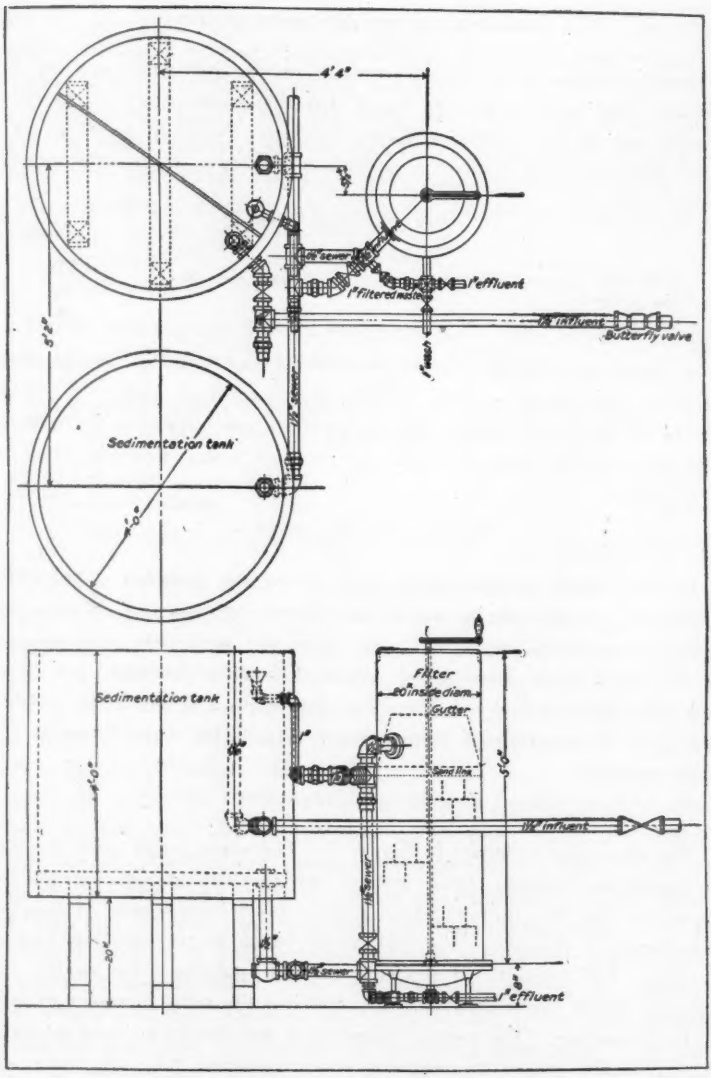



FIG. 1—THE FILTER

connections and valves were provided, as shown in the drawing, so that the influent and the effluent water could be cut off, a stream of wash water could be admitted from the bottom, and the dirty wash water,

overflowing from the top, could either be wasted thru the sewer connection or returned to the sedimentation tanks. The device for stirring the sand during washing was operated by hand. Wash water was supplied from an elevated tank under such a head that a maximum flow of 25 gallons per minute, or 12 gallons per square foot per minute, was possible. A flow of about 8 gallons per square foot per minute was generally used. Suitable connections were also made between the bottoms of the sedimentation tanks and the sewer. A 50-gallon barrel at the end of the sewer line served as a measuring tank for the wash water

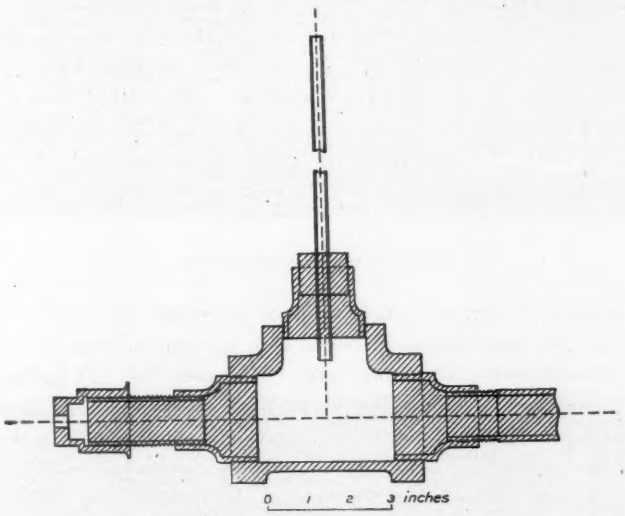



FIG. 2

or the sludge. The rate of flow thru the filter was regulated at the outlet by a standard orifice, a sectional view of which is shown in Figure 2. The orifice itself was a trifle over seven-sixteenths of an inch in diameter. The brass cap containing the orifice was screwed over a nipple of 1-inch pipe, which was in turn connected with a 2-inch tee. The opposite side of this tee was connected by a short pipe to the valve regulating the outflow, and a glass tube, fitted to the upper opening of the tee, permitted the static head on the orifice to be read at any time. The large sectional area of the tee as compared with that of the orifice reduced the velocity of approach to a negligible value. This device was roughly calibrated in the field and was subsequently carefully cali-

brated by discharging into a large measuring tank. The rough field values were found to be substantially correct.

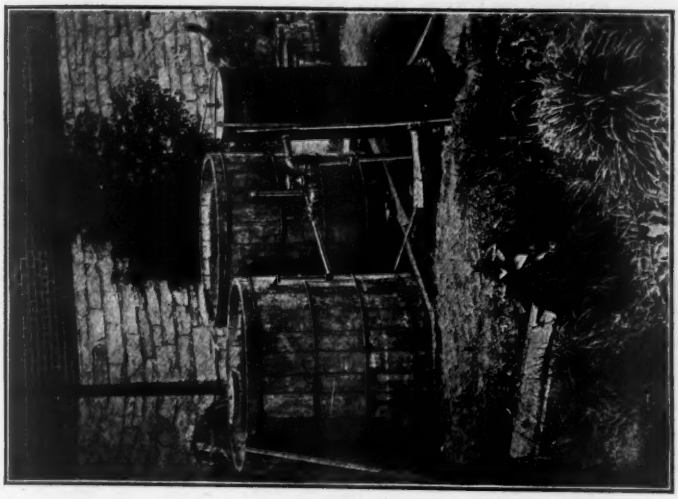
The rate of inflow to the tanks was adjusted to the rate of filtration by the butterfly valve, actuated by a float in one of the tanks (not shown). The filter was filled to a depth of 3 feet with clean 16–30 beach sand, *i.e.*, sand which will all pass a screen with 16 meshes to the linear inch and be retained on a screen with 30 meshes. The water line was 18 inches above the surface of the sand.

The appearance of the filter and sedimentation tanks as they were set up is well shown in Plate II. Plate II, *A*, shows the sedimentation tanks, the influent pipe and controlling valves, and the lever arm of the float operating the butterfly valve. Plate II, *B*, shows the filter itself, the loss-of-head gage, and the connections with the tanks and the sewer. To the extreme right is the measuring tank, and passing between the two tanks on the ground the wash-water pipe line can be seen. The outlet of the filter is hidden from view behind the mound of earth in the foreground.

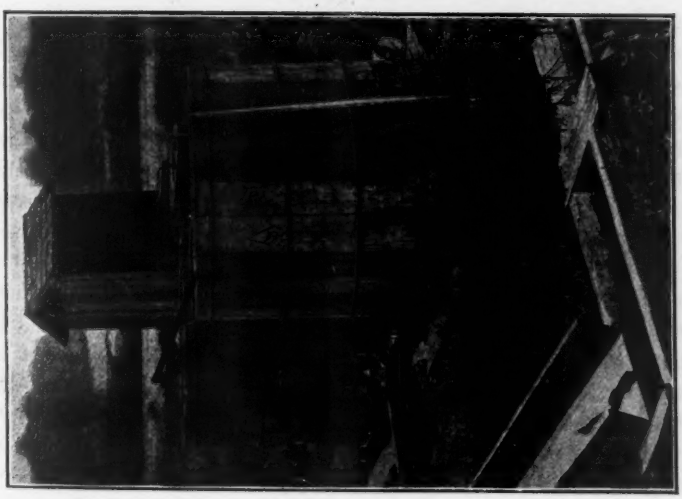
### *Preliminary Sedimentation*

A number of tests were first made to determine the rate of change in the loss of head during filtration with varying periods of preliminary sedimentation. A uniform rate of filtration of 3.25 gallons per minute, equivalent to a rate of 100,000,000 gallons per acre per day, was maintained. The capacity of each of the sedimentation tanks was 300 gallons to the overflow line, so that one tank alone gave a mean storage capacity of one and one-half hours and the two tanks taken together three hours. During the first series of tests both sedimentation tanks were used. The following table shows the relation of loss of head to the quantity of water filtered, the run in question being a fair average of the five made in this way. The results of all the five tests were practically identical.

PLATE II



*B.* Experimental Filter, Sedimentation Tanks, and Measuring Tank



*A.* Sedimentation Tanks and Float Regulator

RELATION OF LOSS OF HEAD TO QUANTITY OF WATER FILTERED

| Time. | Elapsed time. | Quantity filtered. | Loss of head. |
|---|---|---|---|
| | Minutes. | Gallons. | Inches. |
| 9.35 A.M. | . | . . | 4 |
| 9.50 A.M. | 15 | 49 | 7 |
| 10.05 A.M. | 30 | 98 | 8 |
| 10.30 A.M. | 55 | 178 | 12 |
| 1.40 P.M. | 55 | 178 | 11 |
| 2.00 P.M. | 75 | 211 | 14 |
| 2.30 P.M. | 105 | 308 | 20 |
| 3.00 P.M. | 135 | 406 | 28 |
| 3.30 P.M. | 165 | 504 | 40 |
| 4.00 P.M. | 195 | 600 | 55 |

Between 10.30 A.M. and 1.40 P.M. test shut down. No liquor.

The maximum loss of head possible was 55 inches. The mean results from the above and four similar tests gave 585 gallons of water filtered before the loss of head was total.

One of the sedimentation tanks was then cut out of service and the period of sedimentation correspondingly reduced to one and one-half hours. Four runs to determine the maximum amount which could be past under the conditions gave a mean result of 575 gallons, in practical agreement with that of the first series. It is apparent that a period of one and one-half hours was sufficient for the removal of that portion of the suspended matter which can be removed by sedimentation. An examination of the water during sedimentation in a glass vessel tended to confirm this conclusion. The suspended matter appears to be of two distinct kinds. One is very finely divided and light and does not settle out even on prolonged sedimentation. The other is granular and heavy and settles rapidly and completely. It was not convenient with the apparatus at hand to reduce further the period of sedimentation. The laboratory experiments quoted earlier in this paper indicated that a period of one hour would accomplish practically the same result as more prolonged sedimentation.

### *Amount of Wash Water*

The pressure on the wash-water pipe line was sufficient to give an upward flow thru the filter of 25 gallons per minute, or about 12 gallons per minute per square foot of surface. In practise, flows of 8 to 10 gallons per square foot per minute were used. After each of the test runs just described, the filter was washt with an amount of water varying from 50 to 100 gallons for two and one-half to five minutes, the wash water being carefully measured. Observations of the surface of the filter showed plainly that the shorter period of washing was sufficient and that the longer periods did not in any case increase the quantity filtered during the succeeding run. The material deposited on the surface was exceedingly light and finely divided, and required but little water for its removal. The stirring device used was not well adapted to the purpose, since there was little penetration of the sand by the suspended material. An air blast or some device which would thoroly agitate the surface before washing would undoubtedly make possible the use of still less wash water. Allowing 50 gallons for each wash, with an average quantity of 575 gallons per run filtered, gives a little less than 9 per cent. wash water.

The loss of head in these tests bears out a fact of general observation, that the loss of head increases at a fairly constant rate during the run. Such being the case, it is quite evident that with a deeper filter the quantity filtered between washings would be proportionately increased. The amount of wash water would, on the other hand, remain constant or increase but slightly. It is therefore safe to say that with a filter having an available loss of head of 9 to 12 feet an average run of six hours or more could be maintained and the amount of wash water could be reduced to less than 5 per cent.

### *Disposal of Wash Water*

The process, as thus far described, is merely one of concentration of the suspended matter. If the above estimate of 5 per cent. of wash water be correct and the filtered water be used for washing, the net result of the process would be the separation of 95 per cent. of the water in comparatively clean form, leaving the total suspended impurity in the remaining 5 per cent. of the water. This water might be spread upon a small area of land to evaporate, it might be evaporated by artificial means, or, if preferable, it might be filter prest; but the most

economical way to dispose of it is to return it directly to the sedimentation tanks. The material on the filter is so prest together into small lumps that it settles rapidly. The problem of the ultimate disposal of the sludge from the tanks will be taken up in another place.

### *Character of Effluent*

Complete chemical analyses of the waters before and after treatment during these experiments were neither desirable nor feasible. The determination of the total organic solids contained in the waters is the only analytical determination which would be of service in estimating the efficiency of the process. This determination might have been made by the usual indirect method, *i. e.*, by the difference between the total and the fixt or mineral solids. That determination is, however, not well adapted to field conditions, and small changes in the organic content would be entirely masked by the relatively large amount of mineral residue present. It was found in the laboratory studies on the waste liquor that estimating the efficiency of the various precipitation methods on the basis of this organic-solids determination, and also on the basis of the oxygen-consumed method, gave practically the same results. In other words, the organic matter present is fairly homogeneous in character, as might well be expected, and the oxygen-consumed figures, altho purely relative, are therefore a reliable measure of the amount of organic matter present. This test, therefore, and the determination of the turbidity, or suspended solids, by the well-known Jackson turbidimeter method, were used in this work to determine the quantity of the organic and the suspended matter, respectively.

During the two three-hour runs samples for analysis were collected every ten minutes from the raw liquor, sedimented liquor, and final effluent, the small samples being mixt together to obtain an average sample for the run. In both cases the rate was maintained at 3.25 gallons per minute. The following data of the test were obtained:

DATA FROM TEST RUN OF FILTER

| Test number. | Duration. | Loss of Head. | | Quantity filtered. |
|---|---|---|---|---|
| | | Initial. | Final. | |
| | Hours. | Inches. | Inches. | Gallons. |
| 7 | 2.9 | 4 | 55 | 566 |
| 8 | 3.0 | 3 | 55 | 585 |

The chemical analyses for the two sets were very similar. The following table shows the mean values obtained:

ANALYSES OF RAW LIQUOR, SETTLED LIQUOR, AND EFFLUENT

| | Parts per million. | Per cent. removed. |
|---|---|---|
| *Raw liquor.* | | |
| Oxygen consumed: | | |
| Total | 9,400 | . . |
| Dissolved | 2,000 | . . |
| Suspended | 7,400 | . . |
| Suspended solids | 28,000 | . . |
| *Settled liquor.* | | |
| Oxygen consumed: | | |
| Total | 6,200 | 34 |
| Dissolved | 1,600 | 20 |
| Suspended | 4,600 | 38 |
| Suspended solids | 4,400 | 84 |
| *Effluent.* | | |
| Oxygen consumed: | | |
| Total | 2,200 | 77 |
| Dissolved | 1,700 | 15 |
| Suspended | 500 | 93 |
| Suspended solids | 575 | 98 |

The appearance of the effluent frequently changed materially during the run. Contrary to expectations and general experience, the best effluent was always obtained during the early part of the run. The very first portions of effluent were generally slightly turbid, after which a perfectly clear water came thru, as a rule, entirely free from suspended matter. This state of affairs continued until the loss of head had reached about 6 or 8 inches, when the effluent suddenly became turbid and continued so uniformly until the end. The inference was that under a tension or pull on the surface film represented by about 6 to 8 inches of head the finely divided matter contained in the liquor was pulled thru

the surface and then thru the filter. It was thought that if this should be a correct interpretation of the phenomenon, it might be obviated in one of two ways—by increasing the toughness of the surface deposit, or by decreasing the size of the sand pores by use of a layer of finer material on the surface. Both of these methods were tried.

To increase the density and toughness of the surface film the surface was covered with liquor, the outlet being closed, and 2 ounces of sulfate of aluminum were added and stirred in. Fifteen minutes were allowed for the formation and settling of the precipitate, and the filter was then started. The following data were obtained.

DATA OF TEST RUN OF FILTER AFTER ADDITION OF ALUM

| | | |
|---|---|---|
| Duration of run | 1.9 | hours |
| Loss of head: | | |
| Initial | 14 | inches |
| Final | 55 | inches |
| Quantity filtered | 370 | gallons |

The chemical analyses resulted as follows:

ANALYSES OF RAW LIQUOR, OF SETTLED LIQUOR, AND OF EFFLUENT AFTER THE ADDITION OF ALUM

| | Parts per million. | Per cent. removed. |
|---|---|---|
| *Raw liquor.* | | |
| Oxygen consumed: | | |
| Total | 9,000 | . . |
| Dissolved | 1,600 | . . |
| Suspended | 7,400 | . . |
| Suspended solids | 27,300 | . . |
| *Settled liquor.* | | |
| Oxygen consumed: | | |
| Total | 6,000 | 33 |
| Dissolved | 1,600 | 6 |
| Suspended | 4,400 | 40 |
| Suspended solids | 4,500 | 84 |
| *Effluent.* | | |
| Oxygen consumed: | | |
| Total | 1,800 | 80 |
| Dissolved | 1,600 | . . |
| Suspended | 200 | 98 |
| Suspended solids | 450 | 98 |

The improvement of this effluent over that obtained without a coagulant is decided, but is hardly sufficient to warrant the extra cost of treatment. Previous studies had shown that it was necessary to add to the volume of waste on the surface of the filter at least 2 ounces of alum in order to bring about a satisfactory precipitation of the lime. Any less amount would not have produced a satisfactory precipitation in a short time. The total quantity filtered during the run was 370 gallons. This gives an amount of sulfate equal to a little over 2 grains per gallon for the entire run, or a consumption of 300 pounds of alum per million gallons. At a cost of 1 cent per pound (based on net weight

of sulfate of aluminum in the crude compound) this would amount to $3 per million gallons of waste, or 10 cents per ton of finished board. This additional cost for chemicals, together with the slightly additional expenditure for labor and water required by more frequent washing, would not seem to be justified in general by the slightly increased purity of the effluent. The results are given here and the cost estimated as a matter of record and in order to show what could be accomplished by the process if it were deemed desirable in any special case.

The second plan for preventing the small suspended particles in the liquor being drawn thru the surface was to use a surface layer of fine sand. A suitable grade of sand was obtained locally and screened thru a No. 20 screen. The sand thus prepared contained a considerable amount of rather fine material. Mechanical analysis showed that it had an effective size of 0.26 mm. and a uniformity coefficient of 2.0.

A 6-inch layer of the sand was placed on the top of the filter and washt. After washing, the surface was examined and found to consist of a well-mixt layer of coarse and fine material. Two runs were made with the filter as thus prepared. The following are the average data obtained:

DATA OF TEST RUN OF FILTER AFTER ADDITION OF FINE SAND

| | | |
|---|---|---|
| Duration of run | 2.3 | hours |
| Loss of head: | | |
| Initial | 6 | inches |
| Final | 55 | inches |
| Quantity filtered | 440 | gallons |

The appearance of these effluents was such that chemical analyses were not made. They were essentially like the others, and there was no advantage in the use of the layer of fine sand which could in any way offset the obvious disadvantage of the much shorter run.

### *The Sludge*

*Amount and Composition.*—Thruout the experiments, except for the first few runs, the dirty wash water from the filter was run back into the sedimentation tanks. Eventually, therefore, all the material removed from the waste liquor was accumulated in the bottom of these tanks. At the conclusion of the experiments, which consisted altogether of 12 runs, dealing with a total of 4,900 gallons of the waste, the liquor was drawn off from the tanks as far as possible and the depth of accu-

mulated sludge and remaining liquor was measured. The average depth was found to be 6 inches. After thoro mixing, a sample of the sludge was collected and allowed to stand in a glass cylinder for two hours. From a column of sludge 12 inches in depth a 2-inch layer of clear liquid separated at the top, leaving the depth of sludge on the bottom 10 inches. Therefore the 6 inches of sludge and liquor left in the tank was composed of 5 inches of sludge and 1 inch of water, so that 5 inches represents very closely the average depth of sludge in each tank and will be used in the calculations which follow.

Analysis of the sludge gave the following results:

ANALYSIS OF SLUDGE RESULTING FROM FILTRATION OF STRAWBOARD WASTE

| | | |
|---|---|---|
| Specific gravity | 1.094 | |
| Total solids | 19.4 | per cent. |
| Volatile | 9.8 | per cent. |
| Fixt | 9.6 | per cent. |

From these data the following results are obtained:

| | | |
|---|---|---|
| Sludge in tank | 78 | gallons |
| Liquor treated | 4,900 | gallons |
| Per cent. of sludge (by volume) | 1.6 | |

From 1,000,000 gallons of waste there will be obtained:

| | | |
|---|---|---|
| Sludge | 79 | cubic yards |
| Dry solids | 28,000 | pounds |
| Organic solids | 14,100 | pounds |
| Mineral solids | 13,900 | pounds |

For each ton of strawboard there will be produced:

| | | |
|---|---|---|
| Sludge | 4.7 | cubic yards |
| Dry solids | 1,680 | pounds |

A glance at Plate I, *B*, will indicate what these figures mean. The piles of straw there shown represent three months' supply for a mill producing 30 tons of board per day. Over one-third of the total weight of this straw will appear in the waste liquor.

*Properties and Uses of the Sludge.*—As is indicated by the analysis, the sludge is a thick mud. It is dark, muddy brown in color, and has the odor of straw. On exposure to the air it dries much more rapidly than would be expected, owing largely to the action of the air on the free lime. If allowed to dry in a mold, the resulting cast comes away

clear and has taken a very clean impression of the mold. It is very brittle by itself. If, however, a little paper fiber be mixt with it before drying, the dry cast is fairly tough. Such a mixture could undoubtedly be used in many places as a cheap substitute for *papier-maché*.

The dry product had a specific gravity of 0.62. It will readily absorb considerably more than its own weight of water. Its porous nature suggests its use as a heat insulator, particularly in refrigerators.

This material possesses a certain value as a fertilizer. It contains a considerable proportion of calcium carbonate, a substance beneficial to cultivated land. It also contains 0.34 per cent. of phosphoric acid in an available form. Its loose, porous nature makes it particularly valuable for use on clay land, as such land is made much more porous by it and at the same time is sufficiently fine to retain the moisture well. This point was well brought out on examining one of the abandoned settling basins. This basin had originally been diked up about 6 feet above the surrounding fields, and had subsequently been completely filled with the sludge. On digging into this deposit, standing water was observed at a depth of less than 2 feet below the surface, altho the ground water level in the adjacent fields was at least 6 feet lower and the field had not been flooded for over a year.

Some experiments have been made with this solid residue as a base for the production of a sulfur dye. Fusion of the substance with twice its weight of a mixture of one part of sulfur and two of sodium sulfide yields a mass containing a considerable proportion, perhaps 20 per cent., of a brown sulfur dye. Purification of the resulting dye from the mass of inert material was not attempted, and further study is required to determine the most satisfactory procedure for the preparation and purification of this dye, but enough has been done to indicate that a low-grade sulfur dye can be made from this waste material. It dyes unmordanted cotton a good warm shade of brown, is fast to hot soap and to sunlight, and compares favorably in color and fastness with dyes on the market selling at 15 cents per pound.

Considerable attention has been given to the problem of finding profitable use for the residual organic matter which is the end product of the filtration processes here recommended. Altho the satisfactory solution of this problem would be highly desirable and would at once assure the treatment of all strawboard waste liquors, it must be remembered that this is merely a question incidental to the main problem. It is believed that the process of sedimentation, followed by mechan-

ical filtration, essentially as described, furnishes by itself a solution of that problem which will prove of financial advantage to the manufacturers and of lasting benefit to all who have an interest in the purity of the streams below. It was therefore not deemed pertinent to the present investigation to pursue further the question of the utilization of the sludge. The suggestions here given, and particularly that in regard to the preparation of a dye, are merely intended to indicate the direction in which, according to the writer's views, future research would bring results of value.

### *Résumé of Method of Treatment*

The following plan of treatment is recommended: The waste water from the beaters should be past thru a properly designed settling tank of such size that it will give a period of about one hour's storage. A tank built on the principle of the Dortmund tank would be preferable to any other, owing to its compactness and the possibility of continuous use. The tank should have a capacity of approximately 1,200 gallons for each ton of board produced per day by the mill.

The water should pass from the tank directly to the filters, which should be built in small units. The filters should have an available loss of head of at least 12 feet, and could be run at a rate of 100,000,000 gallons per acre per day. This would necessitate a filter area of approximately 16 square feet per ton of board produced daily. This figure allows 10 per cent. excess for repairs and washing.

The effluent should be pumped and used again for washing the filter and for beater wash water. It would at all times contain less impurity than does the very last water past from the beaters, and its use during the early part of the washing process could do no possible harm. To insure a proper washing out of the last of the lime from the stock, it would probably be found necessary to complete the washing with fresh water. In any case a saving of one-half to two-thirds of the amount of wash water now used could be realized, the amount of waste liquor being correspondingly reduced. The water used in washing the filter should be returned to the sedimentation tank, and would require no further treatment.

The sludge from the sedimentation tank could be most expeditiously dealt with by filter pressing. There would remain a fairly dry and hard press cake, which would require disposal unless some profitable

use for it be found. Under the influence of the air and sun this material is speedily resolved into mineral matter, forming a sort of soil. It could be spread upon low land in thin layers and would then take care of itself.

Instead of being filter prest, the sludge might be discharged upon small areas of sandy soil where such are available or even upon somewhat larger areas of less porous soil, and allowed to dry out by draining and evaporation. The dry layer of sludge could then be removed and disposed of. No accumulation of the wet material should be allowed. When once dried out and subjected to the action of the sunlight and air it soon becomes harmless, but in deep beds and constantly covered with water it is subject to all the offensive putrefaction described in the case of the sedimentation fields. This process of spontaneous draining and drying out would probably be found the cheaper, but would require a considerable area of suitable land and would also involve more careful supervision. The amount of land required would depend wholly on the quality of the drainage. For average conditions it may be roughly estimated at 1,000 square feet per ton of board produced by the mill daily. The dried sludge would require removal before the application of more sludge.

### *Character of Waste Water after Treatment*

The quality of the effluent from the proposed process is not all that could be desired. In spite of the fact that it is possible to remove over 90 per cent. of the suspended organic matter present in the liquor, the resulting effluent is still putrescible. That is, a bottle of the liquor shut up air-tight and kept at a warm temperature will in the course of a few days undergo putrefactive fermentation. The putrefaction is rather slow, however, and not offensive. In admixture with an equal volume of tap water the effluent does not putrefy even when inoculated with a small amount of sewage.

The fact that the effluent is practically free from gross suspended solids—that is, solids which will settle out on the bed of the stream—is of greater significance than the analytical data. As was pointed out in the earlier discussion of the problem (page 8), by far the greater part of the damage done to the polluted streams is brought about by the deposit of material in the stream beds. The effluent which has past the treatment here outlined will contain no material capable of settling out even in slack water.

The conclusion is therefore justified that the discharge of this effluent into a stream whose minimum flow equals in volume the flow from the mill would not produce a nuisance. With no allowance for a possible diminution of the amount of wash water, if used as suggested above, this means that the minimum stream flow must be at least 0.05 cubic foot per second per ton of board produced daily at the mill. A minimum flow of 0.1 cubic foot per second per daily ton would therefore provide for a generous factor of safety if the stream is reasonably unpolluted at the point of discharge.

The discharge of such an effluent into a stream highly polluted with sewage would probably be accompanied by an aggravation of the conditions already existing. There would, as usual, be a precipitation of the sewage material by the lime of the effluent. In all fairness it could be maintained that the organic matter of the effluent was not contributing to the nuisance. If, therefore, it should be decided that the addition of lime to a sewage polluted stream constitutes a nuisance, further treatment of the effluent would be required to remove this caustic lime. If, on the other hand, as would seem to be reasonable, it should appear that the real pollution of the stream lay in the sewage and the lime was incidental and was there by right, there would be no reason for such further treatment.

### *Cost of the Process*

The cost of the process recommended cannot be discust in detail at this time. It would be largely the cost of installation. The design and construction of a suitable plant require expert attention, and the cost of the plant would depend somewhat on local conditions. The cost of maintenance would be slight. The cost of additional pumping to supply wash water—say 5 per cent. more than the present amount pumped—can be determined readily. The services of one man, who could also assist in the mill part of the time, would be a sufficient addition for running the plant. The power necessary to pump the sludge thru the filter presses, if that plan were adopted, would not be noticeable in comparison with the total power used in the mill. If the sludge were disposed of by the other plan, evaporation and drying in the field, the services of another man would be required.

In conclusion, the following summary of the chief points of the present paper may be made:

## SUMMARY

The present method employed for the treatment of strawboard waste liquor, that of sedimentation in large fields, is unsatisfactory and expensive and proceeds on a wrong principle.

The filtration of the liquor thru sand, so-called mechanical filtration, but without coagulants, after a short period of sedimentation will remove 93 per cent. of the suspended organic solids and 98 per cent. of the total suspended matter determined as turbidity.

Actual experiments have shown that the resulting effluent can be discharged into an equal volume of reasonably pure water without creating a nuisance. In particular, there will be no sedimentation of organic matter. If its discharge into a seriously polluted stream should bring about precipitation of sewage matter and consequent nuisance, the blame should in all equity be fixt on those contributing the sewage.

The sludge resulting from the sedimentation tanks, after pressing or spontaneous drying, is innocuous and makes good soil. It has some value as a fertilizer and is particularly valuable to mix with the clay soils of the Middle West to render them more porous. Other uses for this material are suggested, but they require further study.

The cost of the entire process is sufficiently low to admit of its adoption wherever stream pollution is serious.

CONTRIBUTION FROM THE SANITARY RESEARCH LABORATORY AND SEWAGE EXPERIMENT STATION OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

# STUDIES OF SEWAGE DISTRIBUTORS FOR TRICKLING FILTERS

BY C.-E. A. WINSLOW, EARLE B. PHELPS, C. F. STORY, AND H. C. McRAE

## I. THE GENERAL PROBLEM OF SEWAGE DISTRIBUTION

THE chief technical difficulty in the construction of the trickling, or percolating filter, as it is called in England, lies in securing efficient distribution of the sewage. The liquid must be discharged slowly and evenly over the whole surface of the bed and thoroughly aërated in the process; in other words, it must be distributed in a rain of fine drops. The mechanism adopted differs widely in various disposal plants. Some of the earlier English investigators used tipping buckets and troughs, placed at intervals over the filter, relying on the splash to dose the intervening areas. This method must necessarily produce imperfect results, and the required apparatus is cumbrous and expensive. Other devices are designed to secure a steady overflow from fixed level troughs or pipes. Of these, the most highly developed is the Stoddart distributor, in use at Horfield and other English towns. This is practically a series of channels over the sides of which the sewage overflows continuously, dripping from points on the under side, 360 points being allowed to a square yard. Theoretically this should secure a very even distribution; but the system requires that the channels remain perfectly level and clean, a condition difficult to preserve in practice.

Another series of distributors secures an even spread of the sewage by the use of some form of moving apparatus. The simplest devices of this type consist of a pair of revolving arms discharging sewage in opposite tangential directions, so that they are propelled by their own discharge on the principle of a Barker mill. The Candy-Whittaker

patents cover some of the best known English distributors of this type. More elaborate designs involve the use of power for moving troughs from which the sewage trickles by numerous small openings, or from which it flows in a thin stream over a weir. In connection with the experiments carried out at Birmingham, Scott-Moncrieff installed a large distributor of this pattern, which consisted of a trough revolving on a circular rail at its outer extremity and driven by a small oil engine. At Hanley is a similar trough, which runs back and forth over a rectangular bed, propelled by an electric motor.

There are certain inherent objections to all such movable distributors which have so far seemed almost insuperable to American engineers. Power, or its equivalent hydraulic head, is necessarily involved in all of them. Movable arms and troughs involve structural details which are expensive to construct and which require constant attention; and it may seriously be doubted whether devices of such complexity and delicacy of adjustment could be operated at all under the influence of a severe winter climate. Even in England trouble was experienced at certain plants during the cold winter of 1906–07.

The simplest and most practical of the English methods of distribution is the system of spraying the sewage upward from sprinkler heads arranged at intervals along fixed pipes. Fixed sprinklers of this type have been used for some time at Salford and other English towns, and are planned for the two largest trickling filter plants yet designed in the United States — at Columbus, Ohio, and Waterbury, Connecticut.

The chance of offensive odors is of course increased by the distribution of sewage spray in the air, but the free oxidation probably facilitates purification. At Birmingham a careful comparison has been made of various types of revolving distributors and pressure nozzles. Mr. J. D. Watson reports (*Engineering News*, **58**, 89), as a result of these studies, that spray jets cost $2,500 per acre to install, against $5,000 to $20,000 for moving distributors, and that the beds equipped with the latter were idle as a result of the distributor being out of order from 8 to 28 per cent. of the time. The results obtained with fixed sprinkler heads of course depend largely on the details of their construction, the head available, the spacing of the nozzles, and particularly on the construction of the nozzles themselves.

In the course of the investigations on the purification of the sewage of Boston, carried out at the Sanitary Research Laboratory of the

Massachusetts Institute of Technology, another method, that of gravity distribution, has been devised.

This system, referred to in an address before the Society of Arts, October 12, 1905, and described in the *Engineering News* for August 16, 1906, appears to possess certain distinct advantages. The sewage is distributed in troughs elevated over the filter, from which it drops through holes in the bottom of the troughs onto concave disks below, splashing upward from the disks in a fine spray. It has been used for two years with success at the Boston station, and has since been adopted by the Massachusetts State Board of Health for an experimental filter at Andover, according to an account published in the *Engineering News* of April 11, 1907.

With distributors of almost any type it is possible to combine siphon tanks or other automatic devices for securing intermittency of operation. The increased pressure thus produced at the moment of maximum discharge tends to keep clear any openings which might otherwise clog, and when the sewage is discharged under pressure from perforated pipes the variations in head tend to make the circle of spray both wider and more even. This plan has long been used at Chesterfield and other English towns.

## II. Methods for Measuring the Efficiency of Sewage Distributors

The Stoddart distributor and the various types of movable sprinklers used in England are theoretically perfect, and their failure, when it occurs, is due to structural imperfections or lack of care in maintenance. On the other hand, fixed sprinkler nozzles and the gravity system of distribution cover at best only a portion of the surface of the filter. Since both these latter types discharge sewage approximately in a circle, each nozzle or disk will wet only 78 per cent. of the square area surrounding it. Furthermore, almost all these distributors tend to discharge, for the most part, in one or two concentric rings of the wetted area. Some nozzles, too, discharge unevenly along different radii. It is important to determine how serious these deviations are. Imperfect distribution means that a part of the filter area below is wasted and another part is operated at excessive rates. Yet almost no exact data upon this point are now available. Some experimenters have noted the proportion of the total area wetted by their

sprinklers; but such a standard is, of course, wholly inadequate, since it fails to discriminate the extent of the discharge upon different portions of the wetted area. We have therefore thought it worth while to make a somewhat extensive study of this point, comparing in detail the efficiency of various fixed sprinkler nozzles and of a number of patterns of gravity distributors under various conditions.

For the quantitative study of the efficiency of distribution a meas-

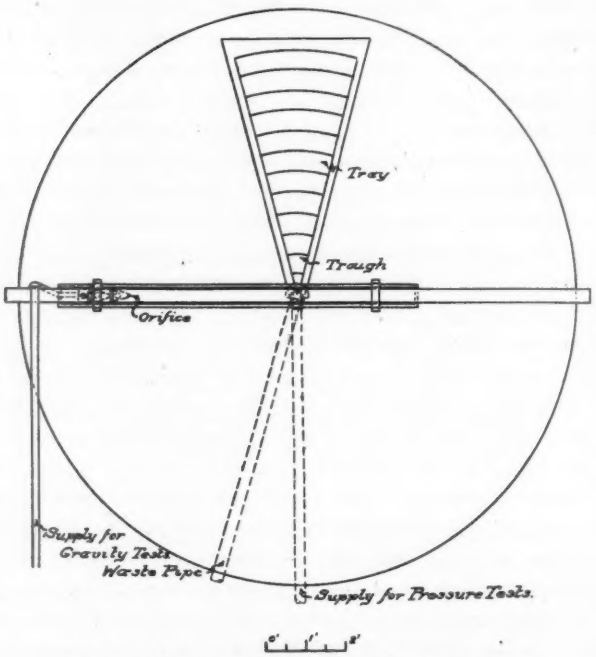



FIG. 1.—PLAN OF APPARATUS FOR SPRINKLER TESTS

uring apparatus was devised, the construction of which is indicated in Figures 1 and 2. It consisted of a shallow, circular basin of cement concrete 14 feet in diameter, sloping toward a central drain connected with a waste pipe below. A 2-inch supply pipe passed under the concrete and rose through this drain at the centre of the basin. To this pipe were attached the sprinkler nozzles of various types designed for pressure distribution. A wooden platform in the shape of the 30° sector of a circle was attached at its pointed end to a 2½-inch

iron collar, fitted over the supply pipe so as to turn freely upon it. The outer end of the wooden platform was supported on ball-bearing castors, arranged to run on a flat shelf at the periphery of the concrete basin, so that the whole platform could be revolved about the supply pipe as a centre; and the collar and castors were so adjusted that the platform

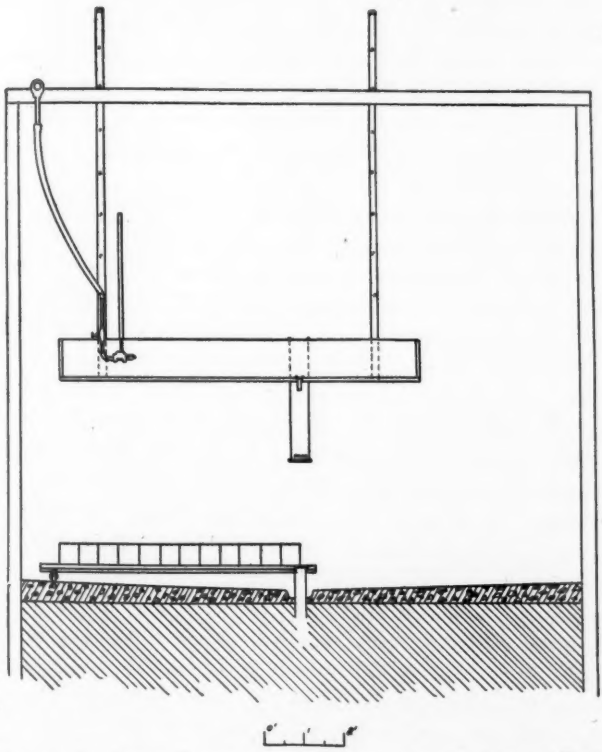


FIG. 2.—SECTIONAL ELEVATION OF APPARATUS FOR SPRINKLER TESTS

was exactly level. The platform carried a galvanized iron tank, also in the form of a 30° sector, divided into compartments by concentric arcs 6 inches apart. The radius of the tank was 6 feet, giving twelve concentric compartments, and its depth was 6 inches. When this tank was rotated about the supply pipe during the course of an experiment, the evenness of distribution was of course measured by the

relative amount of liquid collected in the respective compartments. In various stationary positions the trough recorded radial inequalities.

The supply pipe at the centre of the basin was connected at its outer end with an upright stack of 2-inch pipe made up of short lengths, any desired number of which could be used. At the top of the stack was a wooden box, fed by a hose and relieved by an overflow just below the top. The difference between the water level in this box (varied by removing sections of pipe from the upright stack) and the level of the sprinkler nozzle at the centre of the basin represented approximately the total head effective in distribution. The rate of flow was of course fixed by the head and the sprinkler nozzle used. It was estimated in each test from the total discharge into the measuring tank, and from the time occupied by the run.

The apparatus as shown in Figures 1 and 2 was adapted for the study of gravity distributors by the addition of an overhead trough. This was hung from two timbers passing diametrically across the basin, supported at their extremities by upright studs. At a point fixed over the centre of the apparatus a ¾-inch brass orifice in the bottom of the trough allowed the liquid to discharge upon the splashing disk below.

The uprights supporting the trough were fixed to the cross-timbers above by movable iron pins and the uprights were pierced for the reception of these pins at intervals of 1 foot, so that the distance between the trough and the measuring tank below could be varied at will. The distance between the level of the water in the trough and the top of the tank measured the total head available for gravity distribution. In this system, however, there is another variable. With a given total head, the distance between the point of discharge and the splashing disk and the distance from the splashing disk to the filter may be mutually varied. In our experiments this was provided for by supporting the various splashing disks tested upon a circular lead plate, 6.5 inches in diameter, hung from the distributing trough by four wires. Varying the length of these wires altered the portion of the total head above the splashing disk (called for convenience "head-on-sprinkler").

The rate of flow with this type of distributor is, within limits, independent of the head, so that the rate also had to be taken into account. The rate of discharge was equal to the rate of supply of liquid to the trough, and this supply was measured through a calibrated orifice, indicated in Figures 1 and 2. Two orifices were used in the experiments, one $\frac{7}{16}$ inch and one ⅝ inch in diameter. The orifice plug in

use was connected to a 2-inch tee by a reducing coupling. The section of the tee was large enough to permit an accurate measurement of the static head on the orifice by a glass piezometer tube inserted in its top, and the head was adjusted at any desired point by a valve behind the tee.

The orifices were calibrated by measuring their discharge at various heads in a cypress tank, 2 feet by 6 feet in area and 3 feet deep. A special form of gauge, to be described later, was used in these measurements, and they were accurate within .005 inch in the depth of the tank, or .005 cubic foot of discharge. The calibration of the $\frac{7}{16}$-inch orifice is shown in Table I.

TABLE I — CALIBRATION OF ORIFICE

| Head on $\frac{7}{16}$-inch orifice. | Q in cubic feet per minute. | Q in gallons per minute. |
|---|---|---|
| Inches. | | |
| 5 | .228 | 1.71 |
| 6 | .240 | 1.80 |
| 7 | .256 | 1.91 |
| 8 | .276 | 2.06 |
| 9 | .289 | 2.16 |
| 10 | .306 | 2.29 |
| 12 | .330 | 2.47 |
| 14 | .354 | 2.65 |
| 16 | .378 | 2.83 |
| 18 | .400 | 3.00 |
| 20 | .420 | 3.15 |
| 22 | .438 | 3.28 |
| 25 | .468 | 3.50 |
| 36 | .546 | 4.08 |

The discharges of 1.71 and 4.08 gallons per minute, corresponding to 5-inch and 36-inch heads on the orifice, were chosen as two arbitrary rates of discharge for the gravity distributor tests. The $\frac{5}{8}$-inch orifice was tested sufficiently to find a third, higher rate. A head of 18 inches on this orifice was found to give a discharge of 1.1325 cubic feet, or 8.47 gallons per minute, and this was used as the standard rate for high discharges. The entire apparatus was protected during the course of the experiments by a rough wind shield.

The measurement of the volume of liquid collected in the various compartments of the measuring tank during a test was, according to

our original plans, to be made directly, and for this purpose a small stopcock was attached to each compartment. This process proved somewhat tedious, however, and the same end was attained by measuring the depth of the liquid in each compartment at the end of the run, after a careful preliminary calibration of the various compartments.

The depth of water in this measuring tank, and in the cypress tank used for nozzle calibration, was measured by a simple and accurate gauge devised for the purpose, the construction of which is indi-

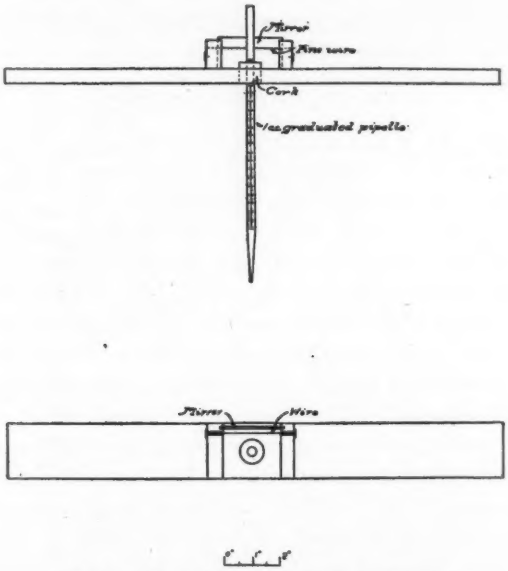



FIG. 3.—ELEVATION AND PLAN OF GAUGE

cated in Figure 3. It consisted of a graduated glass tube (a 1 c.c. pipette), the graduated portion being 6 inches long and divided into hundredths. This tube slid up and down in a cork fitted into a long, flat piece of wood, carefully planed. When the wooden crosspiece rested in a horizontal position, supported at its ends, the tube between was exactly vertical. Just above the wooden crosspiece a fine wire was stretched longitudinally between two supports behind the tube, and behind the wire a small mirror was fixed. By reading with the wire and its reflection superposed the position of the tube could be estimated to tenths of its smallest graduations (.0005 foot). In measur-

ing the depth of water in a compartment of the measuring tank the wooden crosspiece of the gauge was rested on the two sides of the tank and the tube was slid carefully down till its mouth just touched the surface of the water. This point could be detected with great accuracy by the jump into the tube of the drop of water drawn up by capillary action.

Each compartment of the measuring tank was calibrated by pouring in measured quantities of water and reading the depth after the addition of each successive portion. The average of these determinations gave the number of units of depth corresponding to a given volume of water. The reciprocal of this was the volume of water corresponding to a unit of depth for the compartment in question. A special correction was necessary for irregularities in the bottom of the tank and for the zero reading of the gauge. The former was determined by the difference between the change in level produced by the first portion of water poured in and by subsequent portions. The general results of this tank calibration are indicated in Table II.

TABLE II — CALIBRATION OF MEASURING TANK

| Compartment. | Change in depth for one liter added.* | Bottom correction. | Liters per unit change in depth.† | Gallons per unit change in depth. | Relative value (area). |
|---|---|---|---|---|---|
| 1 | .268 | +.020 | .933 | .246 | 1.0 |
| 2 | .187 | . . | 2.674 | .706 | 2.87 |
| 3 | .220 | —.017 | 4.545 | 1.200 | 4.92 |
| 4 | .158 | —.009 | 6.329 | 1.67 | 6.80 |
| 5 | .120 | —.008 | 8.333 | 2.20 | 8.96 |
| 6 | .101 | —.017 | 9.901 | 2.61 | 10.6 |
| 7 | .084 | —.017 | 11.90 | 3.14 | 12.8 |
| 8 | .074 | . . | 13.51 | 3.57 | 14.6 |
| 9 | .065 | —.015 | 15.38 | 4.06 | 16.6 |
| 10 | .059 | —.014 | 16.95 | 4.47 | 18.2 |
| 11 | .052 | —.027 | 19.23 | 5.08 | 20.7 |
| 12 | .048 | —.013 | 20.83 | 5.51 | 22.4 |

* Half a liter for compartment No. 2; quarter of a liter for compartment No. 1.
† Unit = .5 foot.

The "relative values" in the last column of the table should, of course, have come out 1, 3, 5, 7, etc., if there had been no irregularities in the construction of the tank, for with unit depth:

$$Q_1 = \frac{\pi \times 1^2}{4} \times 1 = \frac{\pi}{4}.$$

$$Q_2 = \frac{\pi \times 2^2 \times 1}{4} - \left(\frac{\pi \times 1^2}{4} \times 1\right) = \frac{3\pi}{4} = 3Q_1.$$

$$Q_3 = \frac{\pi \times 3^2 \times 1}{4} - \left(\frac{\pi \times 2^2}{4} \times 1\right) = \frac{5\pi}{4} = 5Q_1.$$

The testing apparatus in operation is shown in Figure 4, and nearer views of the measuring tank in Figures 5 and 6. The following memo-

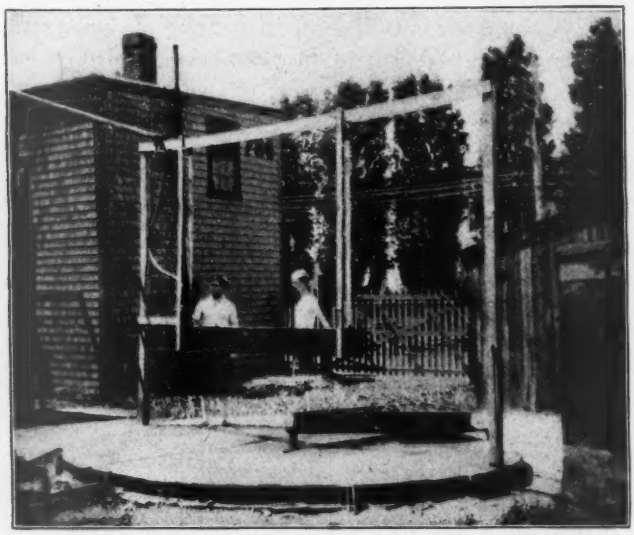


FIG. 4.—GENERAL VIEW OF TESTING APPARATUS WITH TEST IN PROGRESS

randum of the routine procedure in making the test of a gravity distributor may make the working of the whole apparatus somewhat clearer. In beginning a run the measuring tank was emptied, put in place on the wooden platform, and covered with a cover of tar paper stretched over slats. The desired total head was adjusted by raising or lowering the trough, and the head on the sprinkler was regulated by means of the wires suspending the lead plate from the trough. The disk to be tested was then centred on the lead plate just below the ¾-inch opening in the bottom of the trough. The valve supplying the trough was then opened and regulated till the desired discharge was registered on the

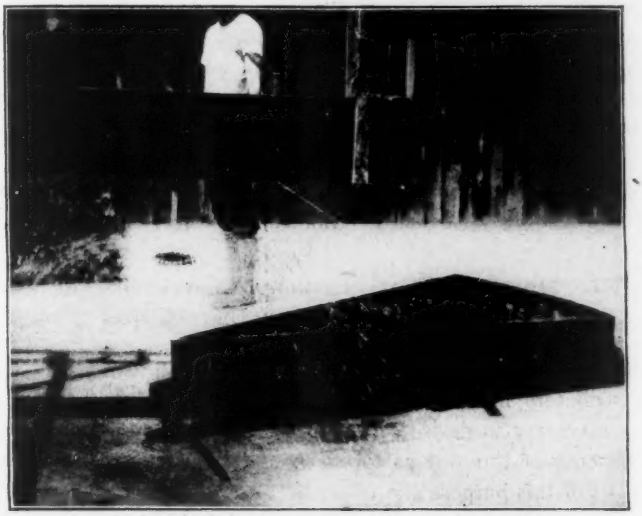


FIG. 5.—SIDE VIEW OF MEASURING TRAY WITH TEST IN PROGRESS, SHOWING TROUGH AND DISTRIBUTING DISK IN PLACE

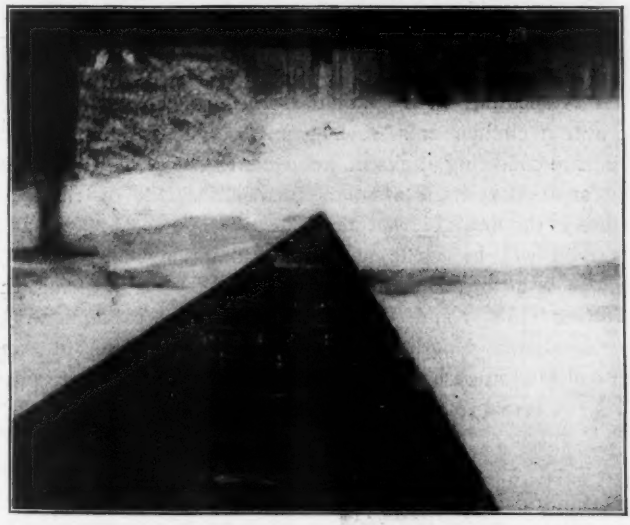


FIG. 6.—VIEW OF MEASURING TRAY FROM ABOVE. TEST IN PROGRESS

piezometer tube. After conditions had become constant in the trough, the cover of the measuring tank was removed (the time being taken with a stop watch). During the test the tank was slowly rotated by hand. As soon as any compartments became so full as to threaten splashing the test was stopped, the cover replaced, and the time again noted. The supply valve was then closed, and after the discharge had ceased the cover was removed and the depth of liquid in each compartment of the measuring tank was determined, as described above.

## III. Method of Calculating a Coefficient for the Efficiency of Sewage Distributors

After the proportionate amount of discharge in various zones about the distributors had been determined by the method outlined above, it was necessary to devise some method of stating the results so that the efficiency of the various types could be easily and accurately compared. For this purpose one of us (E. B. P.) has derived a "coefficient of distribution," which shows the mathematical relation between any observed condition of distribution and that ideal condition in which each small unit of area should receive its exact proportionate share. Professor Phelps' calculations were published in the *Engineering News* of October 11, 1906, and in the Technology Quarterly for March, 1907 (20, 34). The following quotation outlines his method:

"For the purposes of this problem let us assume that a pressure sprinkler is shooting up a spray of sewage fountain-wise, the sewage falling over a circular area. Along any radius let us place a line of small, square collecting tanks of known areas, which we may designate the unit area. Let it be assumed, further, that the distribution along this radius is the mean of that along all radii. The variations along the various radii will be small, and the assumption may be completely realized, as is being done in our experiments, by revolving the line of collecting tanks about the centre during the experiment. After running a suitable length of time, the sewage is shut off, and the amount collected in each small tank is measured. In the accompanying table a set of actual results is reproduced for the sake of illustration.

TABLE III — Results of Observations of Distribution Effected by Sewage Sprinkler

| Tank No. | Radial distance (D). | Sewage quantity (Q). | D × Q. | Excessive quantities (Ex. Q). | D × Ex. Q. |
|---|---|---|---|---|---|
| 1 | 0.5 | 0.8 | 0.4 | . . | . . |
| 2 | 1.5 | 1.6 | 2.4 | 0.14 | 0.21 |
| 3 | 2.5 | 2.7 | 6.8 | 1.24 | 3.10 |
| 4 | 3.5 | 2.5 | 8.8 | 1.04 | 3.65 |
| 5 | 4.5 | 2.3 | 10.3 | 0.84 | 3.78 |
| 6 | 5.5 | 1.9 | 10.4 | 0.44 | 2.43 |
| 7 | 6.5 | 1.5 | 10.0 | 0.04 | 0.26 |
| 8 | 7.5 | 1.3 | 9.8 | . . | . . |
| 9 | 8.5 | 1.0 | 8.5 | . . | . . |
| 10 | 9.5 | 0.6 | 5.7 | . . | . . |
| Totals | 50.0 | | 73.1 | | 13.43 |

$73.1 \div 50.0 = 1.46 = M.$

"In the first column are given the numbers of the collecting tanks, No. 1 being at the centre. In column 2, headed D, are given the distances from the centre of the sprinkler to the centres of the corresponding tanks, the side of the tank being taken as unit distance. In the third column, Q, are given the amounts of sewage measured in each tank at the end of the test. Any unit of volume may be employed. In this case the depths in the measuring tanks are used, these being proportional to the volumes. Now if these quantities, Q, are plotted as ordinates against the corresponding D values as abscissæ, we obtain a curve showing the relative distribution of the sewage along the radius. This curve is shown at A in the diagram (Fig. 7). It shows the rate of discharge per unit area at any point whose distance from the centre is known, and will be known as the curve of radial distribution. Since the radial distribution measured was assumed to be the mean of all radial distributions, the ordinate of this curve at any given distance from the centre shows the rate of discharge at all points on a circumference described about the centre at the given distance from it. Hence to obtain a curve showing the distribution on the whole circle, *i. e.*, on an infinite series of successive circumferences, it is necessary to multiply the ordinate for each point on the radius by the length of the corresponding circumference, or what amounts to the same thing,

relatively, by the radial distance of the point in question. In column 4, D × Q, in the table are given the figures resulting from this operation. These quantities represent the relative rates of discharge of the sewage upon successive concentric rings of the circle, the width of the rings being unity and their distances from the centre being the correspond-

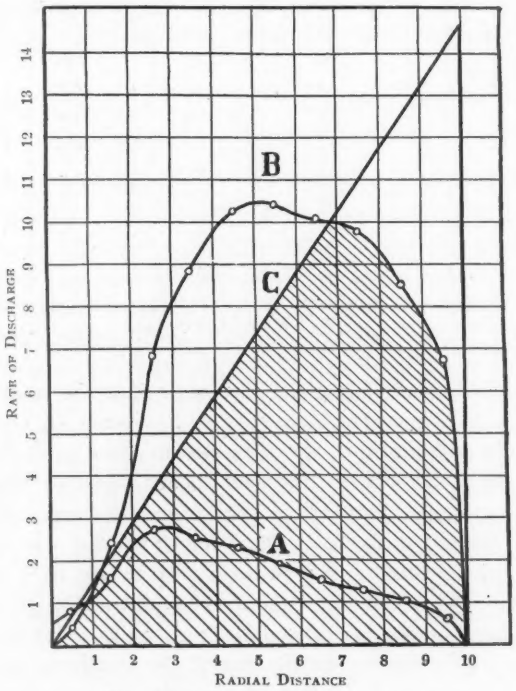



Fig. 7.— Diagram of Distribution

A. Curve of radial distribution. B. Curve of distribution over the circle. C. Curve of perfect distribution over the circle.

ing D. If now a new curve be plotted with these products just obtained as ordinates and the corresponding D values as abscissæ, the resulting curve is the curve of distribution over the wetted area (curve B in the figure).

"From its construction this curve has the following properties: The ordinate at any point shows the relative rate of discharge of the sewage upon a circumference at the corresponding distance from the centre;

the area of any vertical strip shows the relative total discharge upon the corresponding ring of the wetted circle; and the total area under the curve represents the total discharge from the sprinkler.

"It will next be necessary to construct the curve of perfect distribution. This curve must conform to the fact that the discharge upon all unit areas is the same, and hence that discharges upon all circumferences are directly proportional to their lengths, *i.e.*, to their radii. Obviously, then, the curve is a straight line passing through the origin. Its slope is determined graphically by the fact that the area under the curve represents the total discharge from the sprinkler, and hence equals the area under the distribution curve already drawn. The latter area may be determined by means of a planimeter, and from the known base of the triangle its altitude may be computed. It may be calculated more readily but less accurately by adding up the column $Q \times D$, and dividing by the radius of the wetted circle (10). This curve is shown in the figure as curve C.

"We now have the curve of actual distribution and the curve of perfect distribution. There remains to be derived a mathematical expression of the relation between these two curves. The curves have a common area which is shaded in the diagram. From what has preceded it will be apparent that the more perfect the distribution the more nearly will the two curves coincide, and the greater will be this common area. Hence a direct comparison of the common area with the total area of either curve gives a numerical expression of the efficiency of the distribution. If the distribution be perfect the two curves will coincide, and the ratio, common area to total area, will be unity. If the distribution is very poor the common area will be small in proportion to the total, and the ratio will be correspondingly low. Moreover, while it is not so evident from the present brief description of the method, a more careful analysis of the mutual relations of these two curves shows that two distribution curves differing from one another in shape, but yielding the same ratio of common area to total area, represent conditions actually different, but identical as regards relative distribution.

"If we define the term 'excessive discharge' as that part of the discharge from a sprinkler which is flowing upon any area of the filter in excess of the mean rate for the total area (represented graphically by that portion of the area above the straight line), then we may define the coefficient of distribution as the ratio of the total discharge minus the excessive discharge to the total discharge; or, in algebraic form,

$$\text{Dist. Coef.} = \frac{T - E}{T};$$

or, more simply,

$$\text{Dist. Coef.} = 1 - \frac{E}{T}.$$

"Comparisons of the areas may be made quite readily by means of the planimeter. To obviate the necessity of multiplying to get the quantities Q × D, a special form of plotting paper has been used, which performs the multiplications graphically. This paper has one set of coördinate lines vertical, as usual, and the other set radiating from the origin. Direct plotting of the figures used in curve A upon such paper will in reality give curve B, any given value having an actual magnitude upon the plot which is proportional to the horizontal distance from the origin."

While the plot and the foregoing demonstration are essential to a clear understanding of the coefficient, it has been found much simpler and sufficiently accurate in practice to make an arithmetical calculation of the coefficient directly from the observed data. Either of the last two columns in Table II may be used instead of column 2, D, in Table III, since it corresponds to it with an allowance for the irregularities of construction in the tank. For column 3, Q, the observed depth is used, after the application of the proper bottom correction. The sum of the fourth column, D × Q, gives the total discharge, T, upon the sector tested, directly in gallons, if the relative value in gallons is used for D. The sum of column 2, D, corresponds to the total wetted area; that is, it bears the same relation to the total area that the sum of the fourth column, D × Q, does to the total discharge. In practice, when the liquid discharged did not reach the outer compartments, those zones not wetted were of course omitted from column 2. Now if the sum of column 4, D × Q, be divided by the sum of column 2, D, the quotient, M, will be the mean discharge per unit area over the whole wetted surface. If this mean discharge be subtracted from each value of Q which is greater than the mean, a set of figures are obtained which are shown in Table III in column 5, under the heading Ex. Q. These figures are the excessive discharges per unit areas at the respective distances from the centre. Multiplied again by the distances in the D column they give the excessive discharges for the concentric rings, and the sum of the latter figures, column D × Ex. Q, gives the total exces-

sive discharge as already defined, E. In practice, the difference between the mean discharge and the actual discharge was also determined for the zones which received less than their share; and the sum of these values was used as a check on the total excessive discharge, E.

Either the total excessive discharge on the areas receiving too much liquid, or the total deficient discharge on the areas receiving too little, when divided by the total discharge measures the deviation of the distribution from a perfect condition. Referring to Figure 7, it will be seen that the total discharge, T, corresponds to the area under the line C, and that the excessive discharge, E, corresponds to the area below B and above C. Perfect distribution would be indicated by a value of zero for E or a coincidence of lines B and C. This condition is called unity, and the observed condition in any case is expressed as the difference between unity and the ratio of excessive discharge to total discharge. In the shape of a formula this becomes,

$$\text{Dist. Coef.} = 1 - \frac{E}{T},$$

and in the illustrative example given in Table III,

$$E = 13.4,\ T = 73.1,\ c = 1 - 0.18 = 0.82.$$

The crude coefficient thus derived refers to the efficiency of the sprinkler under the given conditions and figured upon the area of the wetted circle. There remains to be derived the true corrected coefficient based upon the total area of the filter, including the unwetted corners between the circles. Each wetted area should be referred to the area of a square whose side is the distance between centres of adjacent sprinklers. Denoting the area of the square by Sq and of the wetted circle by Cir, the corrected coefficient, C, may be found from the crude coefficient, $c$, by the formula,

$$C = c \times \text{Cir/Sq}.$$

This correction will, of course, diminish the crude coefficients to less than 78 per cent. of their value for the wetted area, and all coefficients recorded in our investigation are calculated upon this basis of arrangement in squares. In practice, however, it would be of advantage to arrange distributors, not along two axes at right angles to each other, so that each is at the centre of a square, but on three axes inclined at 120°, so that each is at the centre of a hexagon. With distributors at the centres of squares, the waste area, with no overlap-

ping, amounts to 21.5 per cent. of the whole. With distributors at the centres of hexagons, the waste area amounts to only 9.9 per cent. The hexagonal arrangement makes it possible to put 343 sprinkler heads on an acre instead of 303, spaced with 12 feet between centres, and to raise a rate of 2,000,000 gallons to 2,270,000 without increasing the discharge upon any portion of the wetted area.

## IV. Determination of Coefficients for Gravity Distributors

The system of gravity distribution involves the discharge of the sewage from openings in the bottom of troughs onto concave disks placed below, the discharged stream having sufficient force to splash up and out from the disks in a fine spray.

The splashing disks first used on the Technology trickling filter in 1905 were of metal, 3 inches in diameter, and with a concavity corresponding to a radius of curvature of 6 inches. These were at first placed only 5 feet apart, with a discharge on each disk of less than .9 gallon per minute. This discharge proved too low for good distribution, and a single disk was substituted for four on each 100 square feet in area, giving 10 feet between disks and a discharge on each of 3.47 gallons per minute. This proved far more satisfactory, and the experimental filter thus equipped gave very satisfactory results even through the severe winter of 1906-07. The performance of one of these disks in operation is shown in Figure 8.

With gravity distributors there are three distinct variable factors, the rate of discharge, the distance between the trough and the disk, and the distance between the disk and the filter below. In our experiments we have varied all three independently. For rates we have used the three standard discharges described above, corresponding, respectively, to 1.71, 4.08, and 8.47 gallons per minute. For the total head between the trough and the measuring tank (corresponding to the filter surface) three standard heads were used, 2 feet, 4 feet, and 6 feet; and with each of these total heads three different positions of the disk were tested. With the 2-foot total head the head-on-sprinkler was made 6 inches, 12 inches, and 18 inches; with the 4-foot total head the head-on-sprinkler was made 1, 2, and 3 feet; with the 6-foot total head the disk was placed at 1, 2½, and 4 feet.

Besides these three variable factors the efficiency of gravity distribution depends upon the design of the splashing disks themselves.

FIG. 8.—VIEW OF GRAVITY DISTRIBUTOR IN OPERATION

Twenty-three types of disks were tested in our experiments, varying in size and curvature, in the hope of finding some more favorable design than the simple concave type first used. Cross-sections of the disks examined, with their respective dimensions, are shown in Figure 9.

Nos. 1 to 4 were wooden disks 2 inches in diameter, with surfaces of different degrees of concavity varying from a radius of curvature of 4 inches to one of 20 inches. Nos. 5 to 10 were disks 3 inches in diameter, Nos. 6 and 7 of metal and the rest of wood, the radii of curvature of their concave surfaces varying from 2 to 20 inches. Nos. 11, 12, and 16 were larger, very shallow wooden disks. Nos. 13, 14, 17, 18, and 19 were wooden disks whose upper surfaces were concave about a central raised point, rising again all around their outer edge. We have called this design the mushroom disk. No. 15 was a large, deep metal disk, 5 inches in diameter, and with a 3-inch radius of curvature. Finally, Nos. 20, 21, 22, and 23 were large, 6-inch wooden disks with radii of curvature varying from 4 to 20 inches.

Since each of these twenty-three disks was tested under twenty-seven standard conditions (three subdivisions of each of three total heads at three rates), making over six hundred tests in all, it has not seemed best to publish the mass of figures obtained in detail. The final corrected coefficients are given in Tables IV, V, and VI, arranged first according to the rate of discharge on each disk and then according to the head.

It must be remembered, of course, that the corrected coefficients in these tables take account both of the extent and the evenness of the circle of spray. Some of the disks produced good distribution within a small circle, but the rate on the wetted area was so great as to be excessive. By reducing the crude coefficients for such disks so as to bring the total rate down to 2,000,000 gallons per acre per day, the corrected coefficients have been estimated. This was done for the three rates of discharge tested as follows: A discharge of 1.71 gallons per minute on each splashing disk corresponds to 2,480 gallons per day per disk. At a 2,000,000-rate this requires 808 sprinklers per acre, or one sprinkler to each 54 square feet of filter area; the distance between sprinklers must therefore be 7.35 feet. Similarly the 4.08-gallon rate would require 341 sprinklers per acre, or one to each 128 square feet, and the distance between sprinklers must be 11.3 feet. The 8.47-gallon rate calls for 164 sprinklers per acre, or one to 266 square feet, with a distance of 16.3 feet between sprinklers. All coefficients in the

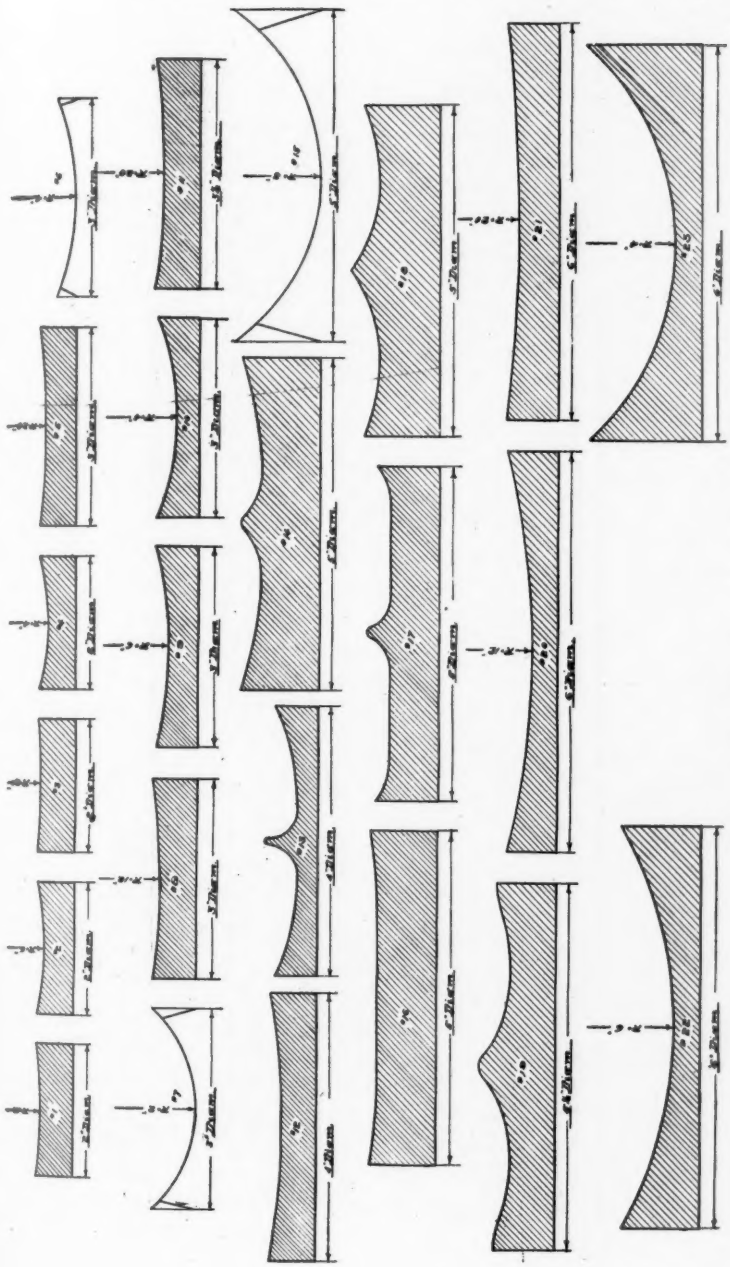


FIG. 9.—CROSS-SECTIONS OF SPLASHING DISKS

TABLE IV — CORRECTED COEFFICIENTS FOR GRAVITY DISTRIBUTORS

Rate on disk = 1.71 gallons per minute. Rate on filter = 2,000,000 gallons per acre per day

| Total head in feet. | Head-on-sprinkler, feet. | NUMBER OF DISK. | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 2 | 0.5 | .05 | .07 | .05 | .05 | .01 | .02 | .05 | .01 | .04 | .05 | . . | .02 | .02 | . . | . . | .02 | . . | . . | . . | . . | . . | . . | . . |
| | 1.0 | .10 | .11 | .06 | .13 | .04 | .11 | .11 | .10 | .04 | .12 | .04 | .04 | .05 | .05 | . . | .04 | . . | .05 | . . | .01 | .04 | . . | . . |
| | 1.5 | .06 | .05 | .10 | .12 | .05 | .10 | .09 | .09 | .05 | .09 | .05 | .04 | .05 | .06 | . . | .03 | .06 | .06 | .02 | . . | .02 | . . | . . |
| 4 | 1.0 | .28 | .28 | .30 | .30 | .18 | .21 | .22 | .17 | .19 | .31 | .15 | .17 | .17 | .16 | . . | .15 | .11 | .10 | .05 | .08 | .09 | . . | . . |
| | 2.0 | .19 | .29 | .29 | .37 | .12 | .27 | .25 | .16 | .17 | .40 | .08 | .10 | .17 | .17 | . . | .08 | .10 | .17 | .05 | .05 | .04 | . . | . . |
| | 3.0 | .18 | .14 | .27 | .27 | .16 | .30 | .30 | .17 | .17 | .23 | .15 | .15 | .16 | .15 | . . | .08 | .13 | .15 | .10 | .01 | .01 | .01 | . . |
| 6 | 1.0 | .29 | .41 | .43 | .42 | .08 | .30 | .36 | .16 | .17 | .40 | .14 | .16 | .27 | .20 | . . | .10 | .17 | .21 | .09 | .04 | .05 | . . | . . |
| | 2.5 | .41 | .43 | .43 | .55 | .38 | .37 | .38 | .25 | .26 | .55 | .33 | .34 | .37 | .29 | . . | .26 | .31 | .38 | .17 | .09 | .04 | . . | . . |
| | 4.0 | .41 | .41 | .41 | .55 | .35 | .50 | .35 | .23 | .26 | .46 | .16 | .18 | .40 | .28 | . . | .14 | .23 | .37 | .16 | .07 | .10 | .12 | . . |

TABLE V—CORRECTED COEFFICIENTS FOR GRAVITY DISTRIBUTORS

Rate on disk = 4.08 gallons per minute. Rate on filter = 2,000,000 gallons per acre per day

| Total head in feet. | Head-on-sprinkler, feet. | NUMBER OF DISK. | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 2 | 0.5 | .05 | .05 | .04 | .05 | .05 | .05 | .05 | .04 | .05 | .05 | .04 | .05 | .05 | .03 | . . | .05 | . . | . . | .02 | .03 | .03 | .02 | . . |
| | 1.0 | .08 | .07 | .07 | .08 | .05 | .08 | .11 | .08 | .08 | .09 | .04 | .06 | .09 | .10 | .04 | .09 | .08 | .09 | .05 | .06 | .05 | .06 | . . |
| | 1.5 | .08 | .08 | .05 | .07 | .05 | .11 | .09 | .08 | .08 | . . | .05 | .08 | .09 | .09 | .06 | .09 | .09 | .09 | .05 | .06 | .06 | .08 | .04 |
| 4 | 1.0 | .20 | .17 | .17 | .18 | .15 | .22 | .20 | .17 | .17 | .22 | .15 | .19 | .18 | .16 | .09 | .18 | .18 | .15 | .07 | .16 | .13 | .13 | . . |
| | 2.0 | .24 | .25 | .23 | .31 | .18 | .35 | .32 | .19 | .26 | .30 | .17 | .21 | .28 | .27 | .09 | .20 | .20 | .27 | .10 | .15 | .09 | .18 | .10 |
| | 3.0 | .19 | .17 | .18 | .25 | .16 | .26 | .40 | .18 | .18 | .31 | .17 | .20 | .26 | .31 | .14 | .18 | .27 | .20 | .13 | .12 | .11 | .17 | .09 |
| 6 | 1.0 | .30 | .29 | .25 | .30 | .24 | .26 | .24 | .25 | .26 | .24 | .23 | .26 | .27 | .25 | . . | .25 | .26 | .29 | .25 | .19 | .17 | .18 | . . |
| | 2.5 | .26 | .46 | .38 | .51 | .38 | .50 | .60 | .41 | .40 | .42 | .33 | .36 | .57 | .54 | .20 | .21 | .35 | .37 | .27 | .27 | .22 | .18 | .11 |
| | 4.0 | .36 | .38 | .28 | .44 | .31 | .56 | .62 | .36 | .42 | .44 | .26 | .32 | .46 | .45 | .25 | .30 | .30 | .33 | .35 | .25 | .18 | .24 | .14 |

TABLE VI—CORRECTED COEFFICIENTS FOR GRAVITY DISTRIBUTORS

Rate on disk = 8.47 gallons per minute. Rate on filter = 2,000,000 gallons per acre per day

| Total head in feet. | Head-on-sprinkler, feet. | NUMBER OF DISK. | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 2 | 0.5 | .03 | .03 | .03 | .05 | .03 | .05 | .06 | .04 | .05 | .05 | .03 | .04 | .03 | .04 | .02 | .04 | .04 | .04 | .04 | .04 | .04 | .03 | .03 |
| | 1.0 | .05 | .05 | .05 | .07 | .03 | .07 | .09 | .05 | .05 | .07 | .04 | .05 | .07 | .07 | .05 | .07 | .07 | .06 | .04 | .05 | .04 | .05 | .04 |
| | 1.5 | .03 | .06 | .04 | .05 | .03 | .09 | .10 | .05 | .05 | .08 | .04 | .04 | .10 | .10 | .07 | .07 | .10 | .08 | .04 | .05 | .05 | .06 | .06 |
| 4 | 1.0 | .10 | .12 | .11 | .14 | .09 | .15 | .14 | .13 | .14 | .15 | .12 | .15 | .15 | .16 | .09 | .14 | .16 | .17 | .09 | .12 | .11 | .10 | .09 |
| | 2.0 | .12 | .12 | .11 | .15 | .09 | .16 | .18 | .11 | .13 | . . | .10 | .12 | .20 | .19 | .11 | .15 | .18 | .19 | .12 | .12 | .10 | .13 | .09 |
| | 3.0 | .11 | .11 | .10 | .16 | .09 | .23 | .24 | .08 | .09 | . . | .10 | .13 | .23 | .24 | .13 | .13 | .20 | .16 | .09 | .12 | .10 | .13 | .09 |
| 6 | 1.0 | .15 | .15 | .16 | .17 | .14 | .18 | .18 | .16 | .16 | . . | .13 | .17 | .20 | .19 | .12 | .15 | .18 | .18 | .14 | .15 | .13 | .13 | .10 |
| | 2.5 | .23 | .23 | .20 | .23 | .16 | .24 | .25 | .21 | .20 | . . | .17 | .20 | .28 | .30 | .17 | .20 | .28 | .30 | .25 | .20 | .20 | .22 | .16 |
| | 4.0 | . . | . . | . . | . . | .19 | . . | .28 | .18 | .18 | . . | .18 | .22 | .32 | . . | .19 | .30 | . . | . . | . . | .18 | .18 | .18 | .14 |

tables have therefore been corrected by referring the actual discharges to squares respectively 7.35, 11.3, and 16.3 feet on a side.

Taking up the independent variables tested in their order it is at once apparent that the efficiency of gravity distributors is markedly influenced by the rate of discharge on each disk, and that about 4 gallons a minute is the most favorable rate. The lower rate, 1.7 gallons per minute, gave very poor results with the larger disks, the liquid merely dripping over the edge. With the smaller disks fairly good results were obtained within a radius of 3 or 4 feet of the disk, although there was generally an excess of discharge nearest the centre. As the distance between sprinklers for this head was only 7.35 feet, the crude coefficients of .6 and .7 were not so greatly reduced as in other cases, and for the smallest (2-inch) disks this rate is better than either of the higher ones. Most of the 2-inch disks gave corrected coefficients of over .4 even with the 6-foot total head, and coefficients of over .5 were obtained for disks 4, 6, and 10.

The intermediate rate of 4.08 gallons per disk per minute did not suit the small, 2-inch disks as well as the lower rate, but with larger disks it gave better results. With good heads the liquid was well distributed, showing neither the concentration near the disk obtained with the lowest rate nor the marked outer ring characteristic of the higher one. Crude coefficients of over .7 were obtained with almost all the disks by using a 6-foot head, and the better ones ranged between .8 and .9. Furthermore, the wetted area was proportionately larger than with the higher or the lower rate of discharge; 4.08 gallons per disk per minute calls for a distance of 11.3 feet between sprinklers, and with high heads the better disks wetted circles 10 and 11 feet in diameter. The corrected coefficients remained, therefore, relatively high, several of the disks showing values over .5, and one, disk No. 7, over .6.

With the highest rate the better disks covered a 10-foot circle, but there was usually a ring of excessive discharge at a distance of 3 or 4 feet from the centre. The larger disks, at high heads, gave crude coefficients of between .7 and .8, wetting a circle of 6 feet radius. Corrected for a 16.3-foot square these crude coefficients are seriously reduced, only two of the corrected coefficients in Table VI being over .3.

The head used with the sprinkler disks was a most important factor in controlling their efficiency. The 2-foot total head proved inadequate in most cases. Some of the crude coefficients were fairly good (between .6 and .8); but the wetted area was always much too

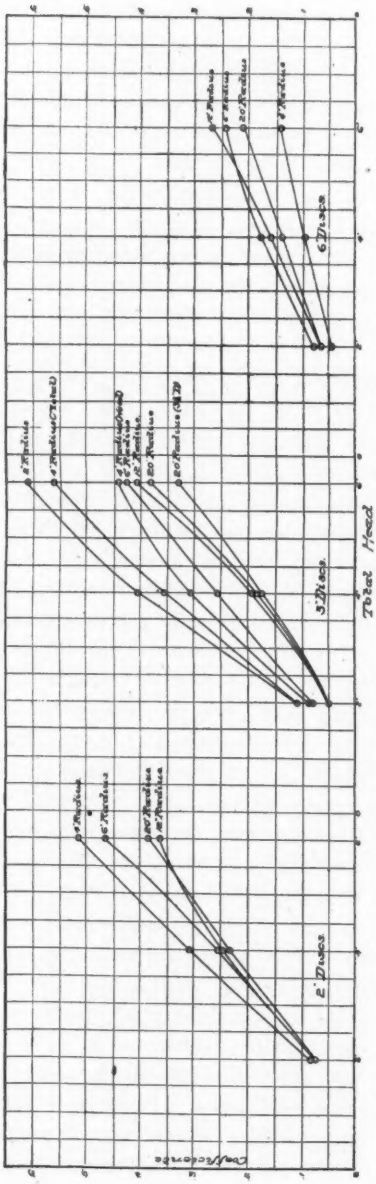



FIG. 10.—RELATION BETWEEN TOTAL HEADS AND COEFFICIENTS FOR DISKS OF DIFFERENT RADII OF CURVATURE
Rate = 4.08 gallons per minute. Best head-on-sprinkler in each case.

small, giving an excessive rate near the sprinkler, and the corrected coefficients were almost always under .1. The 4-foot total head showed better results, and the 6-foot better still, the improved efficiency being directly proportional to the increase in head. This relation is indicated graphically in Figure 10 for the disks of 2, 3, and 6-inch diameters at the best rate of 4.08 gallons per disk per minute. The total heads are plotted as abscissæ and the best coefficients at the different total heads as ordinates. Each curve represents the results for one sprinkler disk, and the fifteen curves are arranged in three groups according to their diameters. The radius of curvature of each disk is indicated on the plot.

With regard to the best proportion of the total head to be used in the discharge above the disk, results are somewhat more variable. Increasing the head on the disk gives an enlargement of the wetted area, but it apparently brings about also an increased tendency to concentrated discharge in a single zone. The figures for the intermediate rate and 6-foot total head at the bottom of Table V include the best coefficients, and are fairly typical of the other results. They show that with a 6-foot total head a head-on-sprinkler of 2½ feet is most favorable for the shallower sprinklers, and a value of 4 feet is better for the deeper ones. The 1-foot head-on-sprinkler is always inadequate to secure a proper splashing discharge. These results are indicated with greater clearness in Figure 11, where the coefficients for the best rate (4.08 gallons per minute) and best total head (6 feet) are plotted for the three values of head-on-sprinkler which were tested. The curves on the diagram otherwise correspond to those of Figure 10. The dimensions of each disk are indicated in Figure 9.

There remains still to be considered the influence of the shape of the splashing disk itself. Two general patterns were studied — simple concave plates and disks of the "mushroom type" with a raised central cone (Nos. 13, 14, 17, 18, and 19). The latter show coefficients intermediate between the large and small concave disks, better than the former and not so good as the latter. In other words, the slope on one side of the central boss deflects the water very much as a simple cup of similar size and curvature would do. The discharge from these disks was, however, unequal along different radii, since it was almost impossible to make the stream of liquid strike the central boss. The coefficients are therefore higher than they should be, since the revolving trough caught portions of unequal discharges in

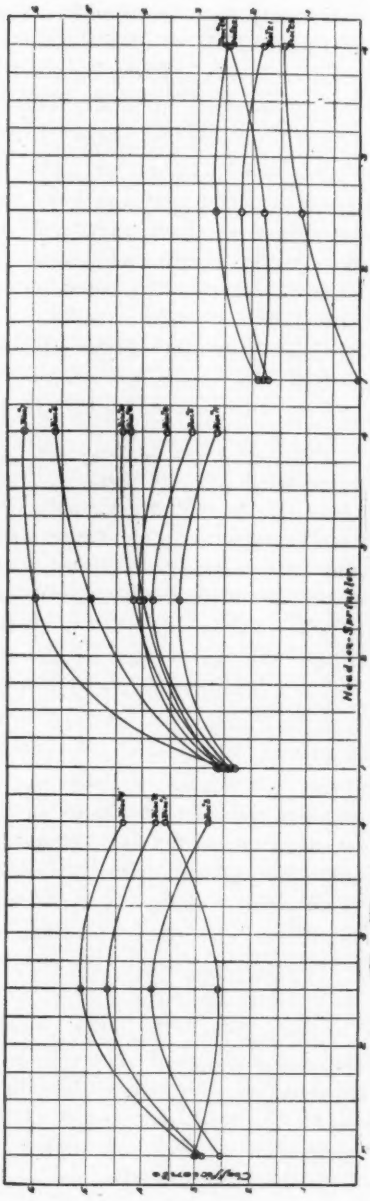


FIG. 11.—RELATION BETWEEN HEAD-ON-SPRINKLER AND COEFFICIENTS FOR DISKS OF DIFFERENT RADII OF CURVATURE
Rate = 4.08 gallons per minute. Total head = 6 feet.

different zones along the various radii. There seems to be no advantage in the use of disks of this pattern.

There remain the simple concave plates, varying in diameter and in radius of curvature. For diameter, 3 inches is clearly the most favorable size. A comparison of the three sets of curves in Figure 10 shows that the 3-inch disks (Nos. 5, 6, 7, 8, 9, and 10) are better than the 2-inch disks (Nos. 1, 2, 3, and 4), and far superior to the larger ones (Nos. 20, 21, 22, and 23). These figures, it must be remembered, relate to the 4.08-gallon discharge. At the lower rate (1.71 gallons per disk per minute) the 2-inch disks give higher coefficients than the 3-inch ones. This might be expected, since poor distribution with large disks arises from the fact that the liquid has not force enough to splash freely off, but pools and drips over the edge. The smallest disks are therefore best suited to low discharges, but the 3-inch disks and 4.08-gallon rate form the best combination.

The effect of varying radius of curvature is well shown in Figure 10 for the 4.08-gallon rate; and the constancy of the relation is indicated by the comparison made in Table VII.

TABLE VII — ORDER OF DISKS ACCORDING TO THEIR COEFFICIENTS
(BEST DISK FIRST)

| Rate, gallons per minute per disk. | Total head. | Diameter of Disks. | | |
|---|---|---|---|---|
| | | 2 inches. | 3 inches. | 6 inches. |
| | | Radii. | Radii. | Radii. |
| | Feet. | Inches. | Inches. | Inches. |
| 1.71 | 2 | 4 6 12 20 | 2 4 4 12 6 20 20 | 20 12 6 4 |
| | 4 | 4 20 6 12 | 4 2 4 6 12 20 20 | 20 12 6 4 |
| | 6 | 4 6 20 12 | 2 4 12 6 20 20 | 6 12 20 4 |
| 4.08 | 2 | 4 6 12 20 | 2 4 4 12 6 20 20 | 6 20 12 4 |
| | 4 | 4 6 12 20 | 2 4 4 6 12 20 20 | 6 12 20 4 |
| | 6 | 4 6 20 12 | 2 4 6 12 20 20 | 12 6 20 4 |
| 8.47 | 2 | 4 6 12 20 | 2 4 4 6 12 20 20 | 6 4 12 20 |
| | 4 | 4 6 12 20 | 2 4 4 6 12 20 20 | 6 12 20 4 |
| | 6 | 4 6 12 20 | 4 2 6 20 20 12 | 6 12 20 4 |

Efficiency evidently increases with the increasing concavity of the disks. Disks Nos. 12 and 16, with very flat surfaces, gave such poor

results that they have not been plotted. The improvement with increase in curvature is most marked with the disks of small diameter, and with the 6-inch disks the 12-inch radius of curvature is the maximum, the 4-inch radius giving very poor results. This is brought out more clearly in Figure 12, where the coefficients at the 4-foot head are plotted against the actual depth of the disks of various diameters. An increase in concavity increases the efficiency of the disk by breaking the liquid up more completely and sending it higher into the air. The accompanying increase of disk surface over which the liquid must travel tends, however, to decrease the efficiency of distribution, probably by

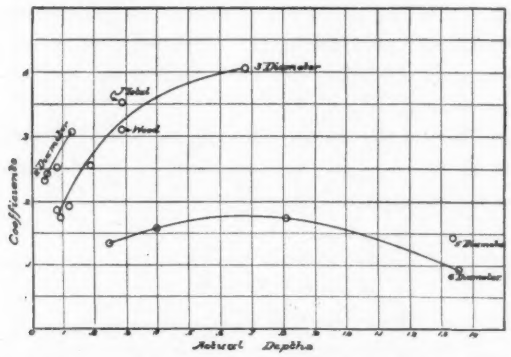



FIG. 12.—RELATION BETWEEN DEPTHS AND COEFFICIENTS FOR DISKS OF DIFFERENT DIAMETERS

Rate = 4.08 gallons per minute. Total head = 4 feet. Best head-on-sprinkler in each case

the greater friction involved. With small disks this is not serious, but as the surface is increased this factor limits the possible increase in concavity. Disk No. 15, with a diameter of 5 inches and a radius of curvature of 3 inches, represents an extreme condition in which the liquid did not splash at all, but eddied about in the deep cup and merely dripped over the edge.

The only other point noted was the effect of the composition of the disks. Nos. 6, 7, and 15 were of metal, spun out of No. 18 sheet copper. All the others were of white pine, turned and carefully smoothed on the lathe, and varnished. No. 15, as noted above, was of very poor shape, but Nos. 6 and 7 gave the best results obtained in the whole series. No. 7 had a 2-inch radius of curvature, and should therefore have given better results than the others, which were of less

concavity. No. 6, however, was of the same size and shape as No. 10 (of wood). Its coefficients were distinctly better under the most favorable heads. Thus at the 4.08-gallon rate, with a 6-foot total head and 2.5-foot head-on-sprinkler, No. 6 gave .49 against .42 for No. 10; with 4-foot head-on-sprinkler it gave .56 against .44.

In general, it appears from this portion of the investigation that the best results with gravity distribution can be obtained under the following conditions:

1. The discharge on each sprinkler should be in the neighborhood of 4 gallons per minute; this means, for a 2,000,000-gallon rate, 340 sprinklers per acre, with a distance between the sprinklers of about 11 feet.

2. The head between the distributing trough and the filter should be as great as possible; 2 feet is inadequate, 4 feet gives fair results, and 6 feet is better. Where exceptional conditions make still higher heads possible, the use of large, deep disks might prove of advantage.

3. The head on the sprinkler should be from 2 to 4 feet. The best subdivision of available total head can probably best be determined by experiments with the disks to be used in each individual case.

4. A simple concave disk of metal seems to promise the best efficiency.

5. The best diameter for the disks appears to be 3 inches. For low rates of discharge smaller disks are better, and for very high rates or very high heads larger ones may be more suitable.

6. Unless the disk be too large it is of advantage to increase its concavity as much as possible. Of 3-inch disks, that having a curvature corresponding to a radius of 2 inches proved most satisfactory. The radius of curvature might profitably be increased toward the limiting value of 1½ inches, which would make the disk a hemisphere. With larger disks larger radii of curvature are necessary.

Of all the disks studied, the best was No. 7, a metal cup, 3 inches in diameter, with a radius of curvature of 2 inches. With a total head of 4 feet and a head-on-sprinkler of 3 feet, it gave a coefficient of .40, the best obtained with that total head; and with a total head of 6 feet and a head-on-sprinkler of 4 feet, it gave the highest coefficient obtained for any gravity distributor, namely, .62.

## V. Determination of Coefficients for Pressure Distributors

The system of spraying sewage upward from fixed sprinkler nozzles under pressure was developed more or less independently at various plants in England. At Salford it was worked out after the failure of various other methods, in which the sewage overflowed from troughs, or was spread by a thin layer of sand covering the filter proper. In the earlier experiments with fixed nozzles, a disk-like cap was placed a little above each in order to break the sewage into a fine spray. Then the attempt was made to break up the stream by the impact of two converging flows; and finally a nozzle was designed which discharged the sewage from a series of openings arranged spirally about a centre. In Derbyshire, Barwise describes as common the use of fixed perforated pipes with metal disks placed over the outlet to form a spray (very much like the earliest Salford type). At Birmingham small sprinkler heads are used, in which the sewage passes up through a narrow, annular opening and is broken up and thrown outward by striking the bottom of a metal plug raised a little above it.

In America the first tests of trickling filter distribution were made at Columbus, Ohio. For the preliminary experiments of 1904–05 a nozzle was designed which recalls that used at Salford. The sewage was discharged through eight ⅛-inch brass pipes, at an angle of 45° with the vertical, into the space between an inner and an outer cone. The sewage left the nozzle in a tangential direction and spread in a fine sheet. Clogging proved too serious an objection to this nozzle, and another design was finally adopted. The latter was described by Mr. J. H. Gregory in the *Transactions of the American Society of Civil Engineers*, 57, 130, as follows: "The nozzle, which is of brass, consists of a single orifice, $\frac{9}{16}$ inch in diameter, with rounded edges, above which, held by two thin arms, is an inverted 90° cone, the axis of the cone coinciding with the axis of the orifice. The jet, on leaving the orifice, impinges against the cone and is transformed into a thin sheet, spreading out radially and breaking into a shower of fine drops. At the points where the sheet strikes the arms the latter are ground down to sharp edges on each side, thereby permitting the sheet to heal up entirely after passing them."

At the Waterbury Experiment Station, Mr. W. G. Taylor has made a careful study of the general operation of sprinkler nozzles, and has devised still another type. He reports (*Engineering Record*, 55, 10)

that a single opening with a cone above for distribution, supported at the sides as in the Columbus nozzle, proved unsatisfactory. The side supports broke the sheet badly, especially after the development upon them of a fungous growth. Furthermore, he points out that the "uniformity of distribution obtained by means of a single cone acting under a head of 5 feet was not satisfactory. Although the efficiency as marked by the area wetted was approximately 75 per cent., a certain outer zone invariably received sewage at a higher rate than the inner area. To lessen this defect, and to secure a greater percentage of wetted area and a more uniform distribution of the sewage, the idea occurred to the writer of placing a lower and secondary cone over the orifice, with the object of intercepting a portion of the sewage and distributing it over the inner fifth of the circular area within the range of the nozzle. The result was effected by boring a hole through the lower cone slightly less in diameter than the fixed orifice in the nozzle, the diameter of the opening in the cone being so proportioned to the diameter of the nozzle orifice that four-fifths of the rising stream passes through the lower cone to be diffused by the upper, and the remaining fifth is sheared off by the lower cone and sprinkled over the central area."

It is evidently desirable to have an accurate measure of the comparative performance of these sprinkler nozzles and of the still better designs which the future will probably develop. Mr. Gregory, in describing the Columbus experiments, was content to say that the nozzle used wetted 77 per cent. of the tributary area "in a perfectly satisfactory manner." Mr. Taylor noted, but did not measure, serious inequalities of distribution within the wetted area. We were therefore particularly glad to apply our method of measuring efficiency to the most promising of these pressure nozzles, and the results have proved significant. Through the kindness of Mr. G. C. Whipple, of New York, we have been furnished with two of the nozzles used at Salford and with the Birmingham type. To Mr. Gregory we owe the Columbus sprinkler, and Mr. Taylor has courteously given us drawings of the Waterbury design. The tests of these five types may best be discussed one by one, and reviewed in comparison with each other later.

The Salford nozzle (old style) is a brass nozzle in the form of a cup, with two openings in the sides at such an angle that the streams discharged upward from them meet in the cup itself. Its construction is shown in Figure 13.

This nozzle differed from all others tested in the fact that it did not discharge equally along different radii. It threw the liquid up in a fan-shaped spray, in quite a narrow plane, as indicated in Figure 14. Our ordinary method of rating efficiency, which assumes symmetrical distribution about the centre, was of course inapplicable under such circumstances. Instead, therefore, of revolving the measuring tank about this sprinkler, we measured the discharge at six different station-

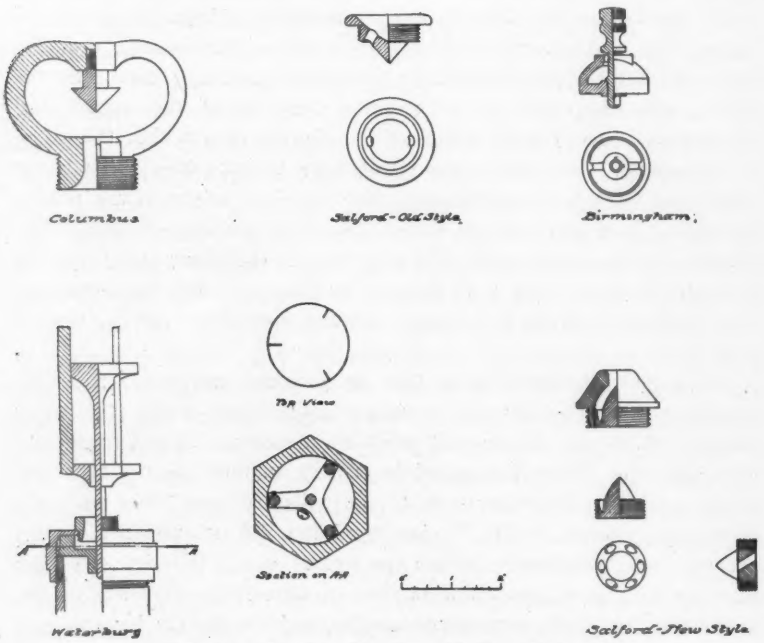



FIG. 13.—TYPES OF PRESSURE NOZZLES TESTED

ary positions, immediately adjacent to each other and together covering one-half of the entire circle surrounding the distributor. The average discharge in each zone was used in the manner described above for calculating the crude coefficient. Then the mean discharge along each sector was determined, and from this the total excessive discharge along those sectors which received more than their share. The ratio of the excessive radial discharge to the total discharge was then determined and taken from unity, giving the "radial coefficient." The

product of the crude coefficient and the radial coefficient measures the evenness of distribution within the wetted area.

When this sprinkler nozzle was tested under a head of 6.4 feet, another anomaly appeared in connection with the determination of the corrected coefficient. The area wetted was larger than the square which would be tributary to each sprinkler at a 2,000,000-gallon rate.

FIG. 14.—VIEW OF SALFORD OLD STYLE NOZZLE IN OPERATION

This means, of course, that at this head and rate the circles would overlap. The following method of calculation was applied in this case and in others of the same kind.

The effect of overlapping circles of spray is exactly the same as it would be if each portion of the spray passing the boundary of the tributary square were perfectly reflected at the side of that square and returned to a corresponding point within. It is necessary, therefore, to calculate how much of the discharge into the outer rings would have been thus reflected, or, in other words, what proportion

of each of the overlapping rings falls without the square. Given the dimensions of the square and of each ring, this is a simple problem in trigonometry, the solution of which gives,

$$\frac{P}{100} = \frac{\cos^{-1}\frac{S}{D}}{45^\circ},$$

in which S is the side of the square and P the percentage of the total discharge into any overlapping ring of diameter D, which would be reflected to an inner ring. Having subtracted from all the rings the amounts which would be reflected, it is next necessary to distribute these amounts among the inner rings where they properly belong. The mathematical solution of this problem gave a result too cumbrous to use. A graphical representation of the conditions drawn on plotting paper, however, indicated readily and with sufficient accuracy the amounts of the reflected discharge which would fall into each of the inner rings affected, and the reflected water was then redistributed. These new values were then recalculated like the others and a coefficient obtained, which referred, not to a circle, but to the area common to the maximum circle and the intersecting square. The relation between this area and that of the square furnished the required factor for the calculation of the corrected coefficient from the crude.

The results of the tests on the Salford old style nozzle are shown in Table VIII. The total head, in this and succeeding tables, is the difference in level between the surface of the liquid in the supply box and the top of the measuring tank. The head-on-sprinkler is the difference in level between the surface of the liquid and the nozzle itself. In general, the nozzle was placed as close as possible to the top of the tank.

One very interesting point about this nozzle is brought out in the column of rates. The discharge with a head-on-sprinkler of 6.2 feet was less than with a head-on-sprinkler of 3.9 feet. This is apparently due to the fact that the two converging streams discharged by this nozzle meet in its cup with such force as to produce a back pressure, which at high heads cuts down the flow appreciably.

TABLE VIII — Coefficients for Salford Old Style Pressure Distributor

| Total head. | Head-on-sprinkler. | Rate, gallons per minute. | Coefficients. | | | |
|---|---|---|---|---|---|---|
| | | | Crude. | Radial. | Product. | Corrected. |
| Feet. | Feet. | | | | | |
| 2.0 | 1.9 | 2.6 | .65 | .56 | .36 | .08 |
| 4.1 | 3.9 | 3.8 | .73 | .53 | .38 | .16 |
| 6.4 | 6.2 | 2.9 | .76 | .58 | .44 | .41 |

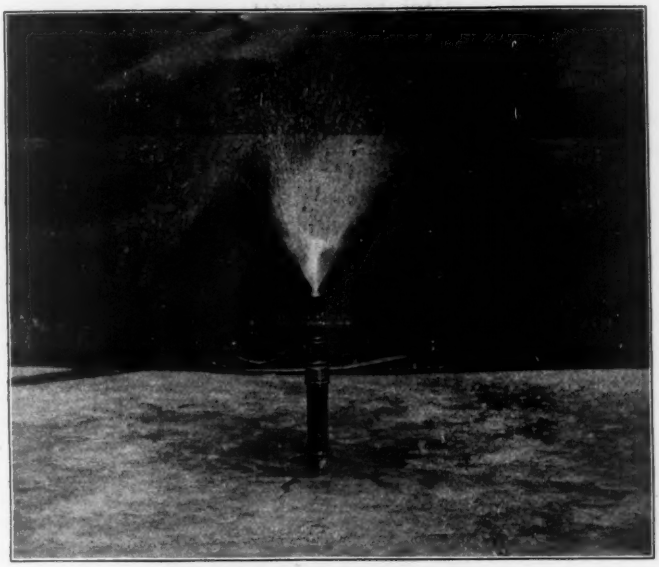


Fig. 15.— View of Salford New Style Nozzle in Operation

It is evident from the column of crude coefficients that this nozzle secures a fairly even distribution within the wetted sector, improving with the head to a very high value. There is an area of excessive discharge near the outer limit of the wetted sector, but the excess is not great. The inequality of distribution along different radii is much more serious. Nearly half the liquid is discharged in excess on one of the six 30° sectors, and this weakness causes the products and corrected coefficients to be poor.

The Salford new style sprinkler tested is a double cone, the outer cone being open at the top. The liquid enters the space between the

cones through six holes of $\frac{5}{32}$ inch diameter, inclined at an angle to the major axis, so that a spiral motion is produced within the inner cone. This sprinkler is shown in Figure 13, and its general method of operation is indicated by the photograph reproduced in Figure 15.

With this, as with the other pressure nozzles, distribution along different radii was approximately equal, and tests were made in the manner described in Section II by revolving the measuring tank about the distributor. Duplicate determinations were made at each of the three heads tested, and the results are shown in Table IX. As in the case of the old Salford nozzle, at high heads a wetted area was obtained extending beyond the sides of the calculated tributary square, and the factor was therefore corrected by the method described above (page 359). The crude coefficients refer in all cases to the actual wetted circles.

TABLE IX — COEFFICIENTS FOR SALFORD NEW STYLE PRESSURE DISTRIBUTOR

| Total head. | Head-on-sprinkler. | Rate, gallons per minute. | Crude coefficient. | Corrected coefficient. |
|---|---|---|---|---|
| Feet. | Feet. | | | |
| 2.2 | 2.2 | 0.7 | .37 | .22 |
| 2.2 | 2.2 | 1.2 | .44 | .16 |
| 4.3 | 3.8 | 1.6 | .68 | .39 |
| 4.3 | 3.8 | 1.7 | .70 | .38 |
| 6.4 | 6.1 | 2.0 | .78 | .67 |
| 6.4 | 6.1 | 2.1 | .77 | .65 |

The results of these tests indicate that the new Salford sprinkler gives very good results at the higher heads. The tests themselves show an excessive discharge on the outer part of the wetted area, but the excess is small, giving crude coefficients of .6 and .7 at 3.8-foot and 6.1-foot heads. At the 3.8-foot head, however, the wetted area (a circle of 3 feet radius) is small in proportion to the rate. The corrected coefficient is therefore poor, while that obtained at the 6.1-foot head, with only slightly higher rate and a circle of 4 feet, remains in the neighborhood of .7.

The Birmingham nozzle, shown also in Figure 13, discharges through a $\frac{3}{8}$-inch opening. Through this opening passes a $\frac{7}{32}$-inch shank, the enlarged upper portion of which breaks up the ascending ring of liquid and sends it out in a fine spray. The working of the nozzle is shown in Figure 16, and its results are indicated in Table X. In

this case the discharge through the opening was so small and the distribution so good that a circle larger than the proper tributary square

FIG. 16.—VIEW OF BIRMINGHAM NOZZLE IN OPERATION

was wetted in every test except those made at the 2.2-foot head. The results are therefore corrected, as in the cases above.

TABLE X—COEFFICIENTS FOR BIRMINGHAM PRESSURE DISTRIBUTOR

| Total head. | Head-on-sprinkler. | Rate, gallons per minute. | Crude coefficient. | Corrected coefficient. |
|---|---|---|---|---|
| Feet. | Feet. | | | |
| 2.2 | 2.0 | 0.9 | .58 | .44 |
| 2.2 | 2.0 | 1.0 | .62 | .38 |
| 4.3 | 4.1 | 1.4 | .80 | .80 |
| 4.3 | 4.1 | 1.5 | .76 | .72 |
| 6.4 | 5.8 | 1.8 | .84 | .69 |
| 6.4 | 5.8 | 2.0 | .78 | .60 |

These figures are of the greatest interest as showing what results may be obtained with a nozzle of small bore so arranged as to break up the stream quickly and completely. With a low rate of discharge, due, of course, to the obstructive construction of the orifice, a relatively large circle was covered (of 2.5 feet radius at the 2-foot head, 4 feet radius at the 4.1-foot head, and 5 feet radius at the 5.8-foot head); and within this circle the distribution was remarkably even. With this nozzle the 4-foot head proved better than the higher one, since at the 5.8-foot head a more definite ring of excessive discharge was formed. Under the best conditions this nozzle gave corrected coefficients of .7 to .8. It is clear that the Birmingham nozzle effects a far more perfect distribution than any other device we have examined.

The Columbus nozzle is designed on a plan exactly opposite to that of the Birmingham sprinkler, in so far as it aims to enlarge the orifice of discharge as much as possible. The Columbus design has been described above, and is also shown in Figure 13. Figure 17 illustrates its method of operation.

TABLE XI—COEFFICIENTS FOR COLUMBUS PRESSURE DISTRIBUTOR

| Total head. | Head-on-sprinkler. | Rate, gallons per minute. | Crude coefficient. | Corrected coefficient. |
|---|---|---|---|---|
| Feet. | Feet. | | | |
| 2.2 | 2.2 | 7.1 | .54 | .12 |
| 2.2 | 2.2 | 7.1 | .60 | .14 |
| 4.3 | 4.3 | 10.9 | .63 | .21 |
| 4.3 | 4.3 | 10.9 | .65 | .22 |
| 6.4 | 6.4 | 14.8 | .61 | .30 |
| 6.4 | 6.4 | 15.8 | .62 | .26 |

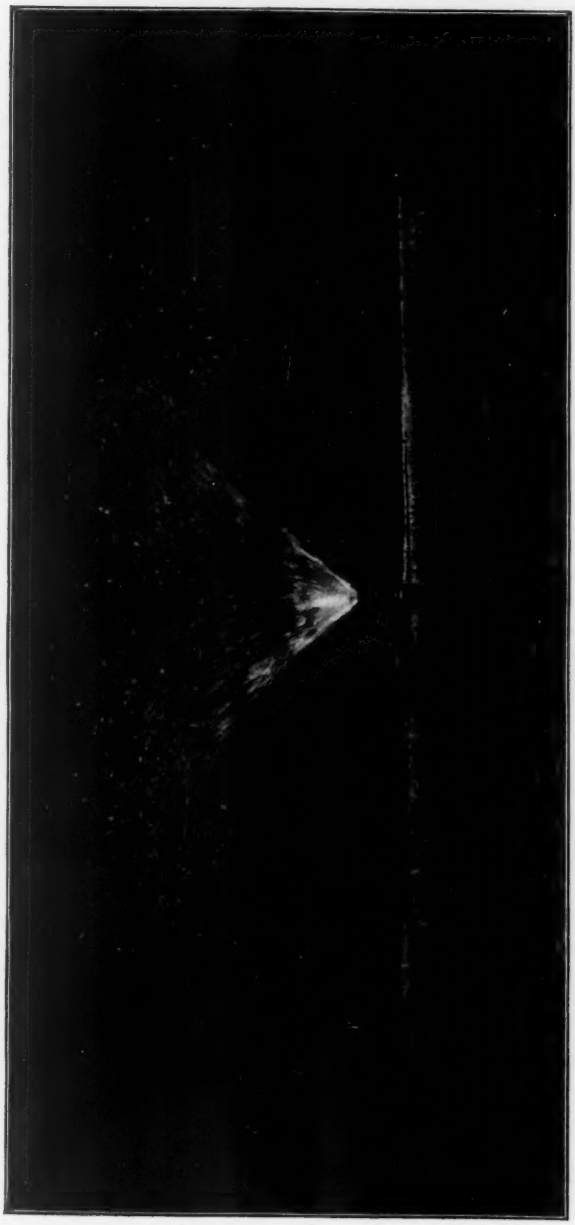


FIG. 17.—VIEW OF COLUMBUS NOZZLE IN OPERATION

The Columbus sprinkler shows at all heads a fair distribution within the wetted area, its departure from the ideal condition being due to the formation of a zone of excessive discharge a little inside the periphery of the wetted area. Crude coefficients, however, are always about .6, and one notable thing about this nozzle is the fact that it gives fairly even distribution even at the 2-foot head. The wetted area is, however, small in proportion to the discharge, and therefore the corrected coefficients are poor. Thus at the 4.3-foot head, for example, the rate of discharge of the nozzle was 10.9 gallons per minute. This discharge, if the total rate on the filter be 2,000,000 gallons per acre, calls for 121 sprinklers per acre, which means a distance of 19 feet between sprinklers. The wetted circle at this head was only 6 feet in radius, so that at an ostensible 2,000,000-gallon rate half the filter area would be working at 4,000,000 gallons and the rest would be idle. It is no doubt for this reason that the Columbus engineers plan to operate at a 4,000,000-gallon rate for half the time, and to rest the whole filter the remainder of the time, spacing their nozzles 16.2 feet apart. This would of course give a distribution more nearly approaching our crude coefficients, though the results at best would be below .6.

The Waterbury nozzle used in these experiments was of the type described on a preceding page (356), in the citation from Mr. Taylor's paper. Its construction is indicated in Figure 13. Briefly the nozzle consists of two cones, one above the other, the lower one perforated at its centre. An annular discharge is in part deflected outward by the lower cone, while its inner portion passes through the lower cone and is deflected by the upper one. As shown in Figure 18, the result is to produce two concentric cones of spray and thus improve the distribution obtained with a nozzle of the Columbus type. In the sprinkler tested by us, the position of each cone in relation to the point at which the liquid leaves the pipe below could be varied by means of set screws, and a number of different settings of these cones were examined. The distance between the lower opening and the lower surface of the lower cone at its outer rim is designated by the letter *a*; the distance between the upper surface of the lower cone and the lower surface of the upper cone is designated by the letter *b*. Reference to Figure 13 will make the significance of these dimensions clear.

FIG. 18.—VIEW OF WATERBURY PERFORATE NOZZLE IN OPERATION

TABLE XII — COEFFICIENTS FOR WATERBURY PRESSURE DISTRIBUTORS

| Total head. | Head-on-sprinkler. | Rate, gallons per minute. | Height of Cones. | | Crude coefficient. | Corrected coefficient. |
|---|---|---|---|---|---|---|
| | | | *a.* | *b.* | | |
| Feet. | Feet. | | Inches. | Inches. | | |
| 2.2 | 2.2 | 5.4 | 1⅜ | 1¾ | .46 | .05 |
| 2.2 | 2.2 | 5.6 | 1⅜ | 1¾ | .45 | .05 |
| 4.3 | 4.3 | 7.6 | ¾ | 1¾ | .53 | .11 |
| 4.3 | 4.3 | 7.8 | ¾ | 1¾ | .62 | .13 |
| 4.3 | 4.3 | 7.5 | 1⅜ | 1⅛ | .62 | .13 |
| 4.3 | 4.3 | 7.7 | 1⅜ | 1⅛ | .62 | .14 |
| 4.3 | 4.3 | 7.6 | 1⅜ | 1¾ | .62 | .14 |
| 4.3 | 4.3 | 7.7 | 1⅜ | 1¾ | .68 | .14 |
| 4.3 | 4.3 | 7.8 | 1⅜ | 1¾ | .66 | .13 |
| 6.4 | 6.3 | 6.8 | ¾ | 1¾ | .68 | .21 |
| 6.4 | 6.3 | 10.2 | ¾ | 1¾ | .72 | .21 |
| 6.4 | 6.2 | 8.6 | 1⅜ | 1⅛ | .62 | .15 |
| 6.4 | 6.4 | 9.6 | 1⅜ | 1⅜ | .69 | .22 |
| 6.4 | 6.4 | 10.4 | 1⅜ | 1⅜ | .73 | .22 |
| 6.4 | 6.2 | 9.3 | 1⅜ | 1¾ | .77 | .21 |

The results of the tests on the Waterbury sprinkler are indicated in Table XII. It will be noticed that the rates varied somewhat under the same conditions. This was no doubt due to the tendency of this sprinkler to clog. Our tests were all made with water, but the tanks through which it was pumped were not perfectly clean and at times contributed their quota of suspended solids (old sewage sludge). These inequalities did not, however, seriously affect the coefficients, which are fairly uniform. It appears from this table that the relative position of the cones does not greatly modify the efficiency of distribution, although there is a slight but distinct improvement in coefficients with an increase in the value of *b*. That is, an increase in the distance between the upper and lower cone improves distribution by throwing the outer cone of liquid further out and separating it more distinctly from the inner one.

In all cases, however, there is more or less fusion of the two cones of spray, and our tests showed a single zone of excessive discharge, not near the periphery of the wetted area, as with the Columbus nozzle, but about a third or a half of the way out from the centre of the wetted circle. The crude coefficients at 4.3-foot and 6.4-foot heads were a little higher than those obtained with the Columbus nozzle, averaging

a little over .6 for the lower and about .7 for the higher head. The wetted area with this nozzle is, however, small for its high rate of discharge. The largest circles wetted were 11 feet in diameter, and this was at rates of about 10 gallons per minute, corresponding to distances of 18 feet between sprinklers. The corrected coefficients are therefore low, the best of them being barely over .2.

Mr. Taylor has worked out certain modifications of his sprinkler which have not been examined in the present investigation, but which well deserve a careful study. Two of these are described in the paper previously cited (*Engineering Record*, **55**, 10) and more fully in a somewhat later one (*Engineering News*, **57**, 238). One consists of a six-winged revolving cone supported directly over a single orifice, through which the sewage rises. The six blades, shaped like air blowers, are rotated by the force of the liquid striking them, and their curvature gives the drops of sewage, leaving them a widely varying angle of elevation. A still more interesting nozzle has a cone similar to that tested in our experiments, but with a vertical cut in each quadrant of the cone. The upper surface of the conical piece has almost the shape of a four-leaf clover, though not cut in so deeply, and the sewage is discharged from the outer rounded corners at a more oblique angle than from the incised areas between. It is hoped that by the proper construction of a cone of this type "the sewage film when leaving shall have such varying angles of elevation that it shall, upon diffusion, throw the proper proportion of drops the distance required to cover the side of the square, while midway between these points, on the diagonal lines, the drops will, by reason of their greater angle of elevation, be thrown with the tendency to fill the corners of the square."

## VI. The Efficiency of Pressure Distributors with Varying Heads

With a sprinkler which, like many pressure nozzles, discharges in a conical sheet and forms an excessive discharge on a peripheral zone, it would seem to be of advantage to vary the head-on-sprinkler in such a way as to cause the zone of excessive discharge to travel in and out over the wetted area. This may easily be done by the interposition of siphon tanks in the supply system, and such is the practice at many of the English plants, notably in Derbyshire (Barwise, "Purification of Sewage," London, 1904). The Board of Advisory Engineers to the

Baltimore Sewerage Commission have suggested a similar arrangement for their projected trickling filters (Report of the Board of Advisory Engineers and of the Chief Engineer, Baltimore, 1906). At Columbus, Mr. Gregory, in the paper previously cited (*Transactions of the American Society of Civil Engineers*, **57**, 130), states that the sprinklers will be operated at a head varying during twenty-four hour periods from 2.75 feet (a rate of 10 gallons per minute per sprinkler) to 5 feet (a rate of 13.5 gallons). We have had a Columbus nozzle with varying head in operation on the trickling filter at the Technology Experiment Station since the summer of 1906 with apparently good results, and the Massachusetts State Board of Health has used a siphon tank in connection with their gravity distributor at Andover (*Engineering News*, **57**, 397).

It is clear that such varying heads must tend to improve the efficiency of devices like the Columbus sprinkler. Just how much improvement is effected under such conditions can, however, only be determined by exact measurement. We have therefore made a study of the operation of the Columbus sprinkler at varying heads, and the results have proved of considerable interest.

We used in our series of tests a maximum head of 4 feet (in two cases 3.7 feet) and a varying minimum head from 3.5 down to 2 feet. The discharge was made from a square siphon tank equipped with float valves so as to start and cut off sharply. The time of filling this tank varied from thirty-seven seconds to three minutes and forty-eight seconds, and the time of its discharge from twenty-seven seconds to two minutes and forty-seven seconds.

The rate in all cases was in the neighborhood of 4 gallons per minute. It was somewhat higher than this in some tests, but the wetted area was in all cases a circle of 10 to 10.5 feet diameter, and the rates corresponded with sufficient closeness to a spacing of nozzles 11 feet apart, on which basis all have been calculated. The coefficients are therefore comparable with those given for a constant head of 4.3 feet in Table XI. These results are reproduced for comparison in Table XIII.

TABLE XIII—Coefficients for Columbus Distributor with Varying Head

| Maximum head. | Minimum head. | Crude coefficient. | Corrected coefficient. |
|---|---|---|---|
| Feet. | Feet. | | |
| 4.3 | 4.3 | .63 | .21 |
| 4.3 | 4.3 | .65 | .22 |
| 4.0 | 2.0 | .45 | .30 |
| 4.0 | 2.5 | .50 | .33 |
| 4.0 | 3.0 | .56 | .37 |
| 4.0 | 3.0 | .56 | .37 |
| 4.0 | 3.2 | .53 | .41 |
| 4.0 | 3.5 | .53 | .41 |
| 4.0 | 3.5 | .55 | .43 |
| 3.7 | 3.5 | .49 | .32 |
| 3.7 | 3.5 | .48 | .38 |

It was expected, *a priori*, that a varying head would give more even distribution within the wetted area; and to the eye the waxing and waning cone of spray looks well-nigh perfect. Nothing could better illustrate the importance of the rigorous method of measurement adopted in these experiments. The crude coefficients in Table XIII are distinctly poorer with varying than with constant heads. An inspection of the original measurements shows the presence of a well-marked zone of excessive discharge just as in the case of the constant head, only not so far out from the centre of the wetted area. A large excess of the liquid was found in the compartments 2 and 2½ feet out from the nozzle. The smaller radial distance 'of this maximum' zone accounts for its greater effect in reducing the coefficient.

On the other hand, the corrected coefficients were much improved by the intermittent operation. The wetted area was as great as in the tests at a constant head of 4 feet and the discharge was much less. The average rate was as low as 4 gallons per minute per sprinkler. Therefore, for a total rate of 2,000,000 gallons per acre the nozzles could be placed much closer than at a 4-foot constant head (11 feet instead of 19), and the wetted area made to approximate more nearly to the tributary squares. Thus the corrected coefficients for a head varying from 4 feet down range from .3 to .4 against a little over .2 for the constant head of 4.3 feet.

With regard to the best construction for a siphon tank, Table XIII brings out several suggestive points. Taking the maximum heads of

4 feet, it is apparent that the evenness of distribution within the wetted area is better when the tank is not too long in emptying, since the crude coefficients are better with a minimum head of 3 feet and over than with lesser ones. As the minimum head is increased, the corrected coefficient rises still more rapidly, increasing progressively from .30 to .43. This is because the wetted area at 3.2 feet and 3.5 feet minimum heads was somewhat larger than with a lower minimum, while the evenness of distribution was as good as at a 3-foot minimum head. Evidently the best siphon tank is one with a short range of level which will discharge a small volume of sewage at frequent intervals. In our tests the best arrangement was such that the tank filled and emptied in about one minute, the change of head being from 4 feet to 3.5 feet. The decreased maximum head in the last two lines of the table shows an injurious effect on both crude and corrected rates.

The siphon tank used in these experiments was a simple box of square section, but Mr. Taylor (*Engineering Record*, **55**, 10) has suggested a design which promises better results. He points out that on theoretical grounds a nozzle acting under a straight-line variation of head from maximum to minimum, such as that produced by the discharge of an ordinary tank under siphon action, could not lead to perfect results. To produce ideal distribution the head upon the nozzle should vary less rapidly near the maximum point than near the minimum. He found that the rate of the desirable variation was represented by a parabolic line.

## VII. Comparative Efficiency of Distributors of Various Types

The optimum conditions for distributors of various types have been somewhat fully discussed, but a brief comparative summary of their performance may be of interest in closing. We have therefore summarized the results under optimum conditions (4-foot total head for Birmingham, 6-foot for the others) in Table XIV.

TABLE XIV—COMPARATIVE EFFICIENCY OF DISTRIBUTORS OF VARIOUS TYPES

| Type. | Rate, gallons per minute. | Crude coefficient. | Corrected coefficient. | Sprinklers per acre to discharge 2,000,000 gallons per day. |
|---|---|---|---|---|
| Best gravity distributor | 4.08 | .76 | .62 | 341 |
| Old Salford | 2.9 | .44 | .41 | 483 |
| New Salford | 2.1 | .78 | .67 | 667 |
| Birmingham | 2.0 | .80 | .80 | 700 |
| Columbus | 14.8 | .61 | .30 | 94 |
| Waterbury | 10.4 | .73 | .22 | 134 |

The American pressure nozzles, judged on the basis of these measurements, show a low efficiency in distribution. They cover the wetted area fairly well under the best conditions, but their discharge is so excessive that at a total rate of 2,000,000 gallons per acre they leave large waste areas between, and their corrected coefficients are correspondingly low. It must, of course, be remembered that at a rate of 4,000,000 gallons per acre, for which the Columbus nozzle at least is designed, the corrected coefficients would be much higher. Furthermore, the performance of these nozzles may be further improved by the use of varying head, which increases a coefficient of .2 (for 4-foot total head) to .4 (for a head varying between 3.5 feet and 4 feet). This question of varying heads well deserves further study, especially in the light of Mr. Taylor's plan for parabolic variations. The Columbus nozzle offers great advantages in the simplicity of its construction and in its large orifice if its excessive discharge can be overcome by the use of siphon tanks.

The best of the gravity distributors (a 3-inch metal disk with a 2-inch radius of curvature) has given much better results than we had hoped for it. Without the complication of siphon tanks and varying head, it shows a corrected coefficient of .62, double that obtained for the Waterbury and Columbus nozzles under the same conditions. With a 4-foot total head its coefficient is .40, while the Columbus nozzle gives .22 with a similar constant head, and the best Columbus nozzle value with a varying head is only .43. The smallest opening for clogging in the gravity system is the discharge pipe, ¾ inch in diameter, while the diameter of the Columbus nozzle is $\frac{9}{16}$ inch. Furthermore, the accessibility of the whole distribution system makes its maintenance in good condition easy.

The new Salford and Birmingham pressure nozzles produce the most efficient distribution of any of the devices tested. At a 6-foot total head the Birmingham coefficient is .69, and at a 4-foot total head it is still better (.80), the distribution being almost perfect. These good results are, however, gained by the use of nozzles which are extremely liable to clogging. The openings of the new Salford nozzle are only $\frac{5}{32}$ inch in diameter, and the cone into which they discharge is admirably adapted to collect solid materials. The opening in the Birmingham nozzle is a ring only $\frac{5}{64}$ inch in diameter. Its removable plug indicates that even with the carefully screened and septicized sewage of Birmingham it requires frequent attention; and it is difficult to see how any such device could be economically used under American conditions, even with septic sewage. On the other hand, crude sewage can be sprayed by the Columbus nozzle or the gravity distributor without difficulty from clogging.

## BOOK REVIEWS

### Geology of Connecticut[1]

There has lately been issued by the State Geological and Natural History Survey of Connecticut two bulletins giving a *résumé* of the known geology of the state, with a geological map. Bulletin 6 is a "Manual of the Geology of Connecticut," by Professors W. N. Rice and H. E. Gregory; Bulletin 7, a "Preliminary Geological Map" of the state, by Professor H. E. Gregory and Dr. H. H. Robinson. The latter bulletin contains, besides a colored geologic map of four miles to the inch, a sketch of the history of Connecticut geology and a short summary of the formations found within the state. In Bulletin 6, of some 270 pages, the authors give a concise, generalized *résumé*, with such explanatory details as to make the book intelligible to the average lay reader, and the whole is written in a very interesting and simple style. The four chapters treat of the physiography, the crystalline rocks, the Triassic, and the glacial geology.

The authors first discuss the division of Connecticut geographically into the Eastern Highlands, the Western Highlands, and the Central Lowlands; the last is subdivided into a central range of trap hills, an eastern valley (in part that of the Connecticut River), and a western valley (the Farmington-Quinnipiac).

The foliation and faults of the Highland rocks extend approximately east of north to west of south; thus one of the most conspicuous features in the topography of the state is the approximately northeast to southwest trending ridges and valleys. This structure is appreciated when the location of the railroad lines is considered; those running north and south have no heavy grades, costly cuts, fillings, or bridges, while the east and west lines have been constructed and are maintained under great difficulties.

The rocks of the Highlands, mostly gneisses and schists, have been so strongly metamorphosed that so far as known all fossils have been

[1] Connecticut State Geological and Natural History Survey, Bulletins 6 and 7, 1907.

destroyed; this leaves their age in doubt except in those cases where a formation can be traced elsewhere into a fossil-bearing zone. It is thus known that the western portion of the Western Highlands rocks are of Cambrian age (Poughquog quartzite), Cambro-Ordovician (Stockbridge limestone), and Ordovician (Berkshire schist). The rocks of the eastern portion of these Western Highlands, as well as the entire Eastern Highlands, are of unknown age, though almost one-half are metamorphosed igneous.

The Central Lowlands are underlain by reddish brown sandstones and shales with intercalated igneous rocks, all of Triassic age. The red color of the strata, due to the ferric oxide in the cementing material, indicates that it was not deposited in the shallow sea along a coast, as the abundance there of life would afford so much decomposing organic matter as to reduce any ferric oxide present. It was most probably deposited in a tidal estuary, as many layers show mud cracks, raindrop imprints, and tracks of land animals, which were covered and thus preserved by the mud brought by the incoming tide.

The occasional presence of conglomerate along the margins of the deposits, with usually the sandstone and shale in the middle of the area, would indicate that the estuary was in places not much wider than the present extent of the Triassic. This coarse sediment is easily identified as derived from the gneisses and schists of the Eastern and Western Highlands, which then evidently formed the shores of this sinking, trough-like estuary.

Fossils are represented among plants by ferns, equisetes, and gymnosperms; among animals by a shell allied to the fresh-water mussel, numerous fresh-water fishes (many allied to the garpike), and extremely few bones but numerous tracks of amphibia and reptiles, many of the latter being dinosaurs.

Associated with the Triassic sediments are igneous rocks, trap consisting mainly of the minerals augite and labradorite. This trap occurs about halfway between the bottom and top of the sediment, principally in three extensive sheets; the lowest 250 feet thick, the middle and upper 400 to 500 and 150 to 200 feet thick, respectively. Beneath the lowest of these three sheets are one or more intrusive sheets, part of which forms the celebrated "four rocks" in the New Haven region. Through a later, eastward tilting of these rocks the trap sheets outcrop in north to south ridges, though owing to the north to south faults the number of the ridges is multiplied, while the northeast to southwest

faults of central and southern Connecticut, as also the minor anticlines and synclines, cause offsets in and a further multiplication of the ridges.

In the middle of the Western Highlands, in the Pomperaug valley, is an area of Triassic sediment which owes its preservation to the fact that it was dropped down by faults between the harder crystallines. This area, with its included trap sheet, was in all probability once continuous with that of the Connecticut valley.

The Triassic is estimated to have a probable thickness of from two to two and a half miles. At New Haven, which is situated upon the lower half of the formation, a well was sunk 4,000 feet without reaching the underlying crystallines.

The present area of Connecticut, at least its western portion, was probably beneath water from pre-Cambrian time through the Cambrian and Ordovician. The old land lay to the west of the state and east of the present continent, thus contributing sediment from both sides to this area. The subjection of this region to the mountain folding of the Silurian to the Trias gave its rocks their present crystalline character. The force producing the schistosity accompanying this crystalline character came from east of south, giving a steep southeast dip and a northeast to southwest or almost north to south trend. There are many local variations, however, as at Bristol, where the planes of schistosity lie in nearly every point of the compass so as to adjust themselves to the underlying rounded mass of granite gneiss.

At the beginning of Triassic times there thus probably existed in eastern and western Connecticut high mountains, between which lay a trough-like valley which later became an estuary. This down-sinking trough received the sediment washed from these mountains and remained approximately at sea level during the entire Triassic. In the middle of this era volcanic activity took place, resulting in some 1,000 feet of lava flows. Most of this probably flowed quietly forth from some fissures, but explosive phases also occurred, since tufaceous deposits are found both in southern Connecticut and near Mt. Holyoke, Massachusetts.

At the close of the Trias the region of the Central Lowland was raised above the sea, the rise being greater at the west than at the east. This gave the eastward dip to the Triassic beds, and it was evidently sufficient to cause the resultant Connecticut River to turn eastward at Middletown and flow upon the crystallines of the Eastern Highlands. The uplift was accompanied by a complex fracturing of the Triassic

strata and much of the crystallines, causing a series of block faults with usually the upthrow on the eastern side, producing a steep western slope (the fault scarp) and a gentle eastern (the dip of the beds). This gave to Connecticut in late Mesozoic times a topography quite similar to that of the Great Basin of the western United States at present. By the close of the Mesozoic the rivers and atmosphere had planed these block ridges and mountainous highlands down to a low, smooth peneplain.

At the beginning of the Tertiary there occurred an uplift with folding, the uplift being greatest (about one-half mile) in the northwestern portion of the state and sloping southeastward. The increased elevation gave renewed activity to the streams. These eroded into valleys, the softer sandstones and shales of the Triassic much more quickly than the harder trap and crystallines; thus resulted the broader features of the present topography — the Eastern and Western Highlands and the Central Lowland with its north to south ridges of trap.

During Quaternary times the entire state was covered by the continental glaciers, which planed off all partially decayed rock, leaving no gradual transition from solid rock to soil such as occurs in the southern states. At its departure it left the entire region covered promiscuously with glacial *débris*, thus obstructing and deflecting the old water courses and causing the many lakes and waterfalls of the present topography.

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## BOOKKEEPING FOR CORPORATIONS[1]

THE title of this book naturally leads one to expect to find in it a full discussion of methods of accounting and management, and the reader is somewhat disappointed when he finds that it contains practically nothing but forms representing various kinds of securities, accounts, bills, reports, etc. A few definitions and a small amount of explanatory matter appear at various points in the work, but the explanations are often ambiguous and in nearly every case inadequate, while the definitions are far from satisfactory.

[1] Quasi-Public Corporation Accounting and Management. By John E. J. Mulhall. Boston: Corporation Publishing Co., 1905. 198 pp., 8vo.

Viewed as a mere collection of forms the book is all that could be desired, and should prove very helpful to accountants in the lines covered. It would seem, however, that some description of the duties of the various officers in companies conducting the lines of business covered should have been included if the work is to justify its title. Moreover, it strikes one as rather anomalous that no scheme of business organization and no discussion of the functions of various departments, with their interrelations, should have been introduced into a work which purports to be a practical handbook on the organization and accounts of such large and important enterprises as water works, gas works, electric lighting works, electric railways, steam heating plants, and telephone companies. It appears to the writer of this article that the author of the book should either change the title of his work or revise it by incorporating an adequate treatment of the subject-matter which one has a right to expect in a book on corporation accounting and management.

C. W. D.

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## A Handbook of Petrography[1]

This little book by Dr. Weinschenk, Professor of Petrography at the University of Munich, is designed to present to students of geology the principles of petrography in as simple and attractive a manner as possible. No attempt is made to take up the microscopic characteristics of rocks, so that the book is in no sense one intended to take the place of the more extended treatises on the subject, but is essentially a book which will serve as a guide during the first systematic study of rocks in the field and laboratory. The hope is expressed that the subject as presented will serve to incite the student to pursue further the study of this interesting but somewhat difficult subject.

The book is divided into two parts. The first, or general part, is devoted to a brief but quite satisfactory discussion of subjects, a clear understanding of which is essential for the proper classification of rocks; for example, observations on the general structure of igneous rocks, particularly as affected by their mode of occurrence; the characters of "Contact" rocks and of the crystalline schists; observations on the sedimentary rocks; suggestions regarding the study and classification

[1] Petrographisches Vademekum. Dr. Ernst Weinschenk. Freiberg in Br.: Herder, 1907. St. Louis, Mo.: B. Herder. 208 pp., 98 il. 85 cents.

of rocks in the field, in connection with which a table is furnished as an aid. The first part is concluded by a chapter giving a brief description of the common rock-forming minerals as they are observed in practice.

The second, or special part, is concerned with the description of important rock types. About seventy pages are devoted to the igneous rocks, which come first, and about the same number to the sedimentary and metamorphic rocks. After a brief discussion of the chemical compositions of the important rock-forming silicates and of the principal divisions of the igneous rocks, these latter are taken up under four heads, as follows:

I. Orthoclase rocks, those in which orthoclase is the predominating constituent.

II. Plagioclase rocks, those in which plagioclase is the predominating constituent.

III. Soda rocks, those which are characterized by a predominating amount of sodium.

IV. Feldspar-free rocks.

With each species described under these divisions the order followed is: external characters; mineral composition; geological occurrence.

With one or two exceptions the definitions of the various types of igneous rocks will meet the approval of teachers of petrography. English and American petrographers will differ, perhaps, from Dr. Weinschenk in the restricted meaning which he assigns to the term basalt, viz., those dark-colored, finely crystalline or aphanitic rocks, rich in sodium, and would prefer to extend the use of this term to cover also most of those rocks for which Dr. Weinschenk uses the term trap. Some teachers would also prefer to take up the nepheline-syenites as a subdivision of the syenites proper, believing that such treatment is simpler, at least for field use.

The sedimentary rocks are taken up in the following order:

I. Mechanical sediments.

II. Chemical sediments.

III. Sediments of organic origin.

Under each variety we find a discussion of the macroscopic characters, mineral composition, and geological occurrence.

Individual descriptions throughout are brief, concise, and to the point; the illustrations are uniformly excellent and are well chosen; the typographical work is admirable, and the book is of a convenient pocket

size. The use of the book in this country will doubtless be limited on account of its being written in German. It is, however, to be especially recommended to students who intend to pursue advanced geological studies, not alone for its petrographical merit, but for the familiarity with German petrographical terms and usages.

C. H. WARREN.